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PETROGRAPHICAL AND GEOLOGICAL INVESTIGATIONS
OF CERTAIN
TRANSVAAL
NORITES, GABBROS,
AND
PYROXENITES
AND OTHER
SOUTH AFRICAN ROCKS.

AN INAUGURAL DISSERTATION TO OBTAIN THE DEGREE OF
DOCTOR OF PHILOSOPHY.

SUBMITTED TO THE UNIVERSITY OF LEIPZIG.

STANFORD LIBRARY

BY

J. A. LEO HENDERSON, M.E. (Freiberg), M.A.I.M.E.,
JOHANNESBURG, TRANSVAAL.

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VITA.

THE author, James Alexander Leo Henderson, son of John Crosbie Aitken and Elizabeth Henderson, of Protestant faith, was born in London, England, on March 29th, 1874. The years from 1881 till 1892 were spent in South Africa, after which the author proceeded to Europe for the purpose of studying. He was educated first by private tuition, and afterwards at the Boys' Model Primary School, and High School, Durban, Natal. On various occasions between 1889 and 1892 the author was present on several extended journeys around the chief Transvaal and Cape mining districts, preparatory to studying mining engineering at the Royal Saxon School of Mines, Freiberg, Saxony, whither he proceeded in 1892, entering that institution in October of that year. After studying mining, metallurgy, and surveying, under Professors Beck, Brunck, Erhard, Kolbeck, Kretschmar, Ledebur, Papperitz, Richter, Stelzner, Treptow, Uhlich, Weisbach, and Winkler, until December, 1896, he took a first-class degree as mining engineer. The three sessions from Michaelmas, 1896, until Easter, 1898, were spent at the University of Leipzig, studying under Professors Credner, Pfeffer, Wiedemann, Wislizenus, and Zirkel. To all of his Professors the author is deeply grateful.

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THE SOUTH AFRICAN

I.

INTRODUCTORY REMARKS.

SOUTH AFRICA affords a fruitful field of research and work to the petrologist, for it has furnished countless occurrences of eruptive and plutonic igneous rocks, which break through strata of every description, and which are met with at the surface, on the plains and table-mountains of the karoo and veldt, as the immense overflows and beds, conical and dome-shaped hills, diamantiferous pipes and koppies; whilst, underground, the miner is constantly interrupted in the pursuit of the gold reefs or other mineral deposits by the dykes of "greenstone" which he encounters in every direction. As a general rule the miner or field geologist classes these eruptive rocks under the very indefinite field term of "trap rocks" or "greenstones" without further notice, but a great many of the occurrences have been examined scientifically by able English and German geologists and assigned to their respective rock families. In the Transvaal, besides the British, German petrographers, e.g., Cohen, Goetz, Koch, Dahms, and others, as well as the present Transvaal State Geologist, Professor Dr. Molengraaff, have of late years carried out a good deal of petrographical research.

It is proposed in this paper to treat of some norites and allied rocks, which occur in the Pretoria, Rustenburg, and Marico Districts of the Central and Western Transvaal, and, if possible, to demonstrate any connection which they may have with each other, and with kindred rocks, already described by various authors, from these and other localities in the Transvaal and Orange Free State.

In these districts the principal sedimentary rocks are the so-called Magaliesberg Beds, consisting of ferruginous shales, flagstones, schistose sandstones rich in muscovite and sericite, quartzitic sandstones, and quartzites, with intercalated sheets of volcanic rocks. These beds are placed by Penning in his "Klipriver Series," which author also identified them with Cohen's "Schiefersandsteinformation" and Dunn's "Lydenburg Beds"; but Molengraaff names them the "Pretoria Beds" (Pretoria Schichten), and is inclined to place them in the lower beds of the Cape Formation, i.e. the Hospital Hill Series. Hatch, however, disputes Molengraaff's arrangement, maintaining that the Magaliesberg

Beds are identical with the Gatsrand Series, and assigns them to the uppermost place in the upper beds of the Cape System.

On the whole, volcanic activity was greatest during the deposition of the beds of the Cape System, and the eruptive rocks under discussion break through the Magaliesberg Beds, sometimes causing metamorphism of the sedimentary rocks in the neighbourhood. They are met with as large overflows, forming beds or sheets and plateaux, as conical hills, and as dykes. The lowermost rock of this part of the Transvaal is the granite; which crops out by Vredefort in the Orange Free State, again coming to the surface between Johannesburg and Pretoria, and disappearing between the Half Way House and the Six Mile Spruit in consequence of an extensive fault which runs in an east-westerly direction. The granite reappears afresh towards the north in the Springbok Flats, beyond the Zwaartkoppies.

The rocks in question occur in that part of the districts of Pretoria, Rustenburg, and Marico lying between the Magaliesberg hills on the south and the Pilandsberge and Dwarsberge on the north. The geological conditions of this part of the Transvaal have only been indicated by Hübner, Alford, Draper, Molengraaff, Hatch, and others; whilst in Hübner's sketch-map of the Transvaal,¹ and in the geological maps of Haevernick,² Dunn,³ Schenck,⁴ Struben,⁵ De Launay,⁶ Berghaus,⁷ and Hatch,⁸ only the most important strata or igneous rocks have been roughly located and sketched, no attempt at detail having been possible owing to the scarcity of exact geological data at command.

As is to be expected in a new mining country like the Transvaal, the geological observations and maps have been compiled more with a view to the economical than to the scientific interest; but under the able direction of Professor Dr. Molengraaff, after a scientific geological survey of the country, more detailed and reliable data and maps may shortly be expected.

Amongst the igneous rocks in certain districts of the Transvaal and Orange Free State, gabbro and allied rocks appear to take an important place, as a glance at the following list of occurrences will show. So far as the author has been able to discover from the literature

¹ A. Hübner, "Geognostische Skizzen aus Süd-Ost Afrika": Petermann's Mittheilungen, 1872, p. 422. Also, "Die neuesten Forschungen in der Transvaal Republik und dem Matabele Reich": *ibid.*, p. 421, Tafel xxi.

² H. Haevernick, "Geologische Uebersichtskarte von Süd-Ost Afrika" (1: 3,700,000): Petermann's Mittheilungen, Band xxx (1884), Tafel xvi. Also, "Geologische Skizzen aus S.O. Afrika": *ibid.*, p. 441.

³ E. J. Dunn, "Geological Sketch Map of South Africa," 1887, Saunders & McDougall, Limited, Melbourne.

⁴ A. Schenck, "Geologische Entwicklung S. Afrikas": Peterm. Mitth., Band xxxiv (1888); with a "Geologische Skizze von S. Afrika" (1: 10,000,000), Tafel xiii.

⁵ F. P. T. Struben, "Geological Sketch Map of South Africa," Edward Stanford, London, 1896.

⁶ L. de Launay, "Les Mines d'Or du Transvaal," map (1: 17,000,000), p. 160; Paris, 1896.

⁷ Berghaus' Physikalischer Atlas, Gotha (1: 30,000,000).

⁸ F. H. Hatch, "Geological Map of Southern Transvaal" (11.5 miles to the inch), with two sections, 1898, E. Stanford, London, S.W.

on the subject, the following are the only occurrences heretofore petrographically examined and investigated:—

- (1) Cohen, E.,¹ *Hypersthene-Diallage-Gabbro* forming a dyke in granite, 8 miles east of Setigalanga, Lydenburg District, Transvaal.
- (2) Maskelyne,² *Rock-forming Pyroxenite* at the Kornkopje, and also in the Wilfontein Bergen, near Holfontein, south of the town of Lydenburg.
- (3) Cohen, E.,³ mentions *Gabbro* in the Pretoria and Rustenburg Districts.
- (4) Dahms, G.,⁴ investigated a *Gabbro* which forms the principal rock of the Zwaartkoppies, Pretoria and Rustenburg Districts.
- (5) The same author describes a *Gabbro*⁵ from the neighbourhood north of Potchefstroom, a short distance south of this last-mentioned occurrence.
- (6) Molengraaff, G. A.,⁶ found a *Quartz-Gabbro* breaking through the Witwatersrand Beds at the Mooi River, south of Potchefstroom, near the Orange Free State border.
- (7) South of this he also discovered⁷ a *Quartz-Amphibole-Gabbro* which forms a part of the Rhenosterkop in the Orange Free State, not far from the Transvaal border.
- (8) He also describes⁸ another *Quartz-Amphibole-Gabbro* occurring in the dolomite at Otto's Hoop in the Marico District.
- (9) In Bergrat Schmeisser's book⁹ are published the results of Dr. Koch's investigations on *Quartz-Norite* or *Quartz-Enstatite*- (or *Bronzite*-) -Diabase from the farm Drietfontein near the Comet Co.'s Conglomerate bed, Boksburg, Witwatersrand (sample obtained from diamond drill core); also an
- (10) *Olivine-Norite* from the Rand Victoria Mine, Witwatersrand, also obtained from a drill core.
- (11) F. H. Hatch¹⁰ mentions a *Hypersthene-Gabbro, or -Norite*, from the north side of the Magaliesberg hills, 8 miles north of Rustenburg.

¹ "Erläut. Bemerkungen zur Routenkarte von Lydenburg," etc., p. 49; Hamburg, 1875.

² Phil. Magazine, 1879, p. 135.

³ Bericht über die XVI^{te} Versammlung des Oberrh. Geol. Vereins zu Lahr, 29 März, 1883.

⁴ G. Dahms, "Gabbro der Zwaartkoppies," etc.: Neues Jahrb. für Mineralogie, etc., Beil. Band vii (1891), p. 91.

⁵ Ibid., p. 124.

⁶ "Beitrag zur Geologie der Umgegend der Goldfelder a. d. Hoogevelde i. d. S. A. Republik": Neues Jahrb. für Mineralogie, etc., Beil. Band ix (1894), p. 264.

⁷ Loc. cit., p. 286.

⁸ Loc. cit., p. 220.

⁹ "Über das Vorkommen und Gewinnung der nutzbaren Mineralien in der Süd Afrikanischen Republik," 1894, p. 57.

¹⁰ F. H. Hatch, "A Geological Survey of the Witwatersrand and the Districts of the Southern Transvaal": Quart. Journ. Geol. Soc., vol. liv (1898), p. 76.

Cohen¹ also described a Quartz-Diabase free from olivine, from Colesberg, Cape Colony, containing diallage-like augite and primary micropegmatite.

The majority of these rocks contain no olivine. They weather with difficulty, the mineral constituents in hand-specimens taken from rounded boulders or exposed outcrops being nearly always quite fresh. The weathered surface is roughed by protruding grains of the less easily decomposed pyroxenic constituent, and coloured brown by a thin coating of iron-oxides, which result from the decomposition of the ferruginous pyroxenes.

The rocks herein described may be added to the above list of occurrences.

In dealing with the much discussed gabbro family, the following prefatory remarks may not be out of place:—The question as to whether the so-called “diallage” shall be regarded as an independent member of the pyroxene group, or whether the name “diallage” shall be extirpated, and the so-named mineral be simply called Augite, has often been debated by many eminent mineralogists and geologists, e.g., Zirkel, Judd, Rosenbusch, Hintze, Irving, Molengraaff, and others, and therefore may not be gone into in detail here. Zirkel maintains that there is every reason why the mineral should retain its distinctive name, because of its characteristic leafy structure, and its occurrence in rocks of very marked character. Judd² remarks that the diallage is probably only a plutonic form of the common augite, the characteristic structure and inclusions along the so-called “solution planes” being caused by chemical action and pressure. Hintze, again, in his new extensive Mineralogy,³ after giving a short history of diallage, dismisses the matter very summarily, and does not treat the diallage as an independent member of the augite series. He considers the name “diallage” to be superfluous, and comments upon the subject thus:—“However, it is more natural to reject every appearance of independence for the ‘diallage,’ and only to establish the fact that the lamellar structure, which is rendered possible by the nature of the gliding planes after a (100), in the pyroxenes of the gabbros (and in other rocks characterized by the diallage) has attained a very high degree of perfection; at all events, one may speak of a ‘diallage-like structure,’ by which the etymological meaning of Haiiy’s old name of ‘diallage’ also retains its validity.” Irving,⁴ in his investigations on the gabbros of Lake Superior, in a footnote observes that “the distinction between diallage and augite is a valueless one, since not only are both found

¹ E. Cohen, “Geognostisch-petrographische Skizzen aus Süd Afrika”: Neues Jahrb. für Mineralogie, etc., Beil. Band v (1887), p. 236.

² J. W. Judd, “The Secondary Rocks of Scotland” (Second Paper): Quart. Journ. Geol. Soc., vol. xxx (1874), p. 237. Also, “On the Tertiary and older Peridotites of Scotland”: Quart. Journ. Geol. Soc., vol. xli (1885), pp. 379, 385, 387, and 408.

³ Dr. C. Hintze, “Handbuch der Mineralogie,” 1893, p. 1,032.

⁴ R. D. Irving, “The Copper-bearing Rocks of Lake Superior”: United States Geological Survey, Washington, 1883, p. 36.

in the same section, but every gradation is found in the rocks of this class, from augite to diallage." Again, Molengraaff,¹ referring to the monoclinic pyroxene constituents of some South African gabbros examined by him, says: "As soon as one demands a leaf-like structure, i.e. a parting after $\infty P \infty (100)$, as the *conditio sine qua non* for diallage, it will be impossible to designate this augite as diallage; however, in this case one will be compelled at least to speak of a *diallage-like augite*, in that a striation caused by a leaf-like structure after OP (001), present in these pyroxenes, is not totally absent in normal diallage, and the other characteristics, e.g. habit and colour, agree with those of diallage."

Molengraaff's remarks also apply to most of the diallage-like augites in the rocks described in this paper. It has, however, been found that, in many cases, the striation after OP (001) is caused by lamellar mutual intergrowth of diallage and hypersthene, parallel to the above-mentioned plane, as, for instance, in some of the Zwaartkoppies norites. If diallage be regarded as a monoclinic pyroxene characterized by lamellar or leaf-like structure parallel to any pinacoidal plane, and by the characteristic inclusions, together with the brassy metalloid lustre of the rhombic pyroxenes, then these pyroxenes may be termed diallage; but if any one of the above qualities be not present, Molengraaff's term diallage like augites should be used: in the latter case other authors would perhaps call them only augites.

However, without insisting upon its mineralogical independence by the use of this nomenclature, in order to avoid lengthy and tedious descriptions, these diallage-like augites will all be here shortly termed *diallage*. These norites and gabbros consist of a heavy plagioclase with high extinction, and usually two, but sometimes three, varieties of pyroxene.

The separation of the most interesting minerals of these rocks, i.e. the two principal pyroxenes, was a most tedious operation, which caused much loss of time, as both of the pyroxenes were almost non-magnetic, and very heavy, with a specific gravity greater than that of the most commonly used heavy solutions, such as Thoulet's solution or methylene iodide, the latter difficulty being increased in that the two minerals in question differ only slightly from one another in specific gravity, coupled by the fact that both pyroxenes are very intimately intergrown. Thus, after unsuccessful results attending the trials at separation by means of the Thoulet's solution and methylene iodide, as well as by means of magnetism, the Klein's heavy solution had to be resorted to. The latter proved to be a very serviceable liquid in every way, notwithstanding its lesser mobility, which rendered the separation of minerals of almost equal specific gravities the most difficult, and precluded the use of fine grains or powder of the mineral substance. The Klein's solution attains

¹ Loc. cit., p. 287.

a specific gravity of 3·36 at ordinary temperatures, but may be concentrated up to 3·6 in a higher temperature, about 70° C. As in some cases both the pyroxenes possessed a specific gravity greater than 3·36, they could be separated from one another only in a warm concentrated solution, kept at an even temperature, which is very troublesome to work with.

Naturally, in dealing with such intimately intergrown minerals, one could only make use of a very small percentage of the separated diallage or hypersthene for the analyses, namely, only the purest pleochroic hypersthene, and non-pleochroic diallage grains which possessed the extremes of specific gravity. The great bulk of the pyroxenes, which had a medium specific gravity, were of necessity rejected, being in an intimately intergrown condition, since the complete separation of both constituents would be only possible after fine pulverization. In this minute condition the minerals are nearly inseparable in Klein's heavy solution, since the latter is more or less viscous at high temperatures, and in a very concentrated condition.

References to special geological and petrographical literature, consulted by the author, will be given in footnotes where necessary, so that no special mention need be made here of the same.

The geographical distribution of these rocks has been chosen as the order of description, as it proves to be the most feasible method, and the various occurrences will be considered, starting from the east end of the Zwaartkoppies and proceeding in a westerly direction to Marico District.

II.

SPECIAL GEOLOGICAL AND PETROGRAPHICAL DESCRIPTIONS.

THE ZWAARTKOPPIES NORITES.

Professor E. Cohen, of Greifswald, has already described the occurrence of the "Gabbros" of the Zwaartkoppies, and their relations to the nepheline-syenite of the Rustenburg District. A free translation reads as follows¹:—

"Somewhat northward of the Magaliesberg hills, which strike through the middle Transvaal in an approximately E.-W. direction from Pretoria across Rustenburg, runs a second chain of hills, the

¹ See Bericht über die XVI^{te} Versammlung des Oberrh. Geol. Vereins zu Lahr am 29 März, 1883, Stuttgart. Also, E. A. Wülfing, "Untersuchung eines Nephelin-syenit aus dem mittleren Transvaal, Süd Afrika": Neues Jahrb. für Mineralogie, etc., Band ii (1888), p. 16.

so-called Zwaartkoppies. These are composed almost exclusively of gabbro, which shows well-marked changes in size of grain and structure, as well as in the relative proportions of constituents, which is often the case in this family of rocks. In the neighbourhood of Renseburg, and at the Hex River north-east of Rustenburg, for instance, there occur light-coloured typical gabbros, in which the diallage occasionally distinctly recedes. These gabbros change very abruptly into dark-coloured, finer-grained rocks, in which the pyroxene exhibits more of the character of the common augite; at the same time quartz and biotite appear in considerable quantity. In such instances the augite possesses, as a rule, independently defined contours, and only seldom shows those irregular outlines, characteristic of ophitic rock structure. One would therefore designate the rock of the Zwaartkoppies as a gabbro, frequently with diabase-like facies. Intermediate rocks, with diallage and augite, as well as with a very large percentage of biotite and quartz, occur especially towards the east; where the light-coloured typical gabbros appear to be absent.

"Only in one spot, e.g., where the hills bend round in a north-westerly direction, between Renseburg and Rustenburg, do the lower spurs of the Zwaartkoppies consist of nepheline-syenite, which occurs in close proximity with the gabbro, and is probably of inconsiderable distribution. In spite of the apparent local relations to the gabbro, one may take it for granted that this is an independent geognostic body, since no transitions of gabbro into nepheline-syenite were observed, nor are such transitions to be expected with any degree of probability."

The following are some Zwaartkoppies rocks investigated by the author:—

- (i) *Diallage-Norite, from a short distance north of the Zwaartkoppies, about 25 miles N.N.W. of Pretoria.*

This rock, as seen in the hand-specimen, shows a medium-grained crystalline structure, and, on macroscopic examination, the only minerals which can be recognized by the aid of a magnifying-glass are felspar, up to 1 cm. in length, and dark pyroxene, up to 0.5 cm. in length, both very fresh. These minerals are arranged in almost parallel positions to one another, possessing a tabular crystal form, thus imparting a somewhat schistose appearance to the rock; which character is rendered more marked by an inclination to cleave, though imperfectly, along certain planes parallel to those in which the constituent minerals lie.

The felspar possesses glancing cleavage faces, on which the fine twinning striation may be observed, proving it to be plagioclase. The pyroxene appears to be partly automorphic, and grains with well-developed crystal faces are seen protruding from the broken rock surface. A marked striation is often seen on these faces, apparently parallel to the basal plane OP (001), giving one exactly the same impression as the twinning striation on plagioclase crystals.

Under the microscope the rock is seen to be of ideal freshness, and the constituents resolve themselves into (1) water-clear plagioclase, (2) strongly pleochroic pyroxene, (3) very weakly pleochroic pyroxene, (4) colourless to pale-green pyroxene, no other minerals being present, except here and there a little green hornblende, in the hypersthene, and a few black grains of iron-ore. Neither the pyroxenes nor the felspar show well-defined automorphic forms, but are all irregularly bounded by each other, thus imparting a granitoid structure to the rock. The order of crystallization appears to be—(a) felspar, (b) hypersthene, (c) diallage, (d) colourless pyroxene; the coloured pyroxenes, b and c, are evidently of almost contemporaneous origin, being intimately intergrown with each other.

No signs of cataclastic action are to be recognized in the appearance of the rock constituents; therefore the parting of the diallagic constituent cannot be ascribed to that cause. The plagioclase shows the two twinning systems, after the albite and pericline laws so characteristic in plagioclases belonging to the gabbro rock family.

The plagioclase forms the greater part of the rock by volume. The majority of the grains are xenomorphic, giving a high extinction of the twinned lamellæ, up to 37° . This character and its high specific gravity of over 2.7 determine it to be a very basic plagioclase, near the lime end of the felspar series, namely bytownite or anorthite. A little plagioclase with a smaller angle of extinction is also present. The felspar is water-clear, as a rule, but here and there it is clouded by partial decomposition, or by inclusions. In a few crystals an undulatory progressive extinction indicates a submicroscopic zonary structure. Inclusions are fairly numerous, principally being colourless glass negatives, but sometimes, though seldom, the felspar mass is intergrown with a matted sagenite-like network of hairs. Water-clear as well as light-green columnar rods of apatite and pyroxene are also found here and there in different directions. The colourless glass inclusions, which are interesting both because of their arrangement and because of their own enclosures of a dark crystallized mineral, are of almost uniform dimensions, with similar outlines, and lie parallel to each other, arranged along different planes of the plagioclase, principally along the plane of twinning $\parallel \infty \bar{P} \infty (010)$. Different sections of these glass negatives give either flat tabular or lath-shaped forms, according to the direction of the cutting. Dark and well-formed crystals, which, as a rule, are enclosed in the glass negatives, vary from submicroscopic size to well-defined forms, whose angular values can be determined under a strong magnifying power to be about 120° (see Fig. 1, a, β , γ , δ , Plate I). They are almost impellucid, but transmit a feeble brownish light, and represent, in all probability, titanic iron-ore (ilmenite).

In order to determine the chemical composition and specific gravity of the two pyroxenes, and thus to note their differences chemically and gravimetrically, as well as optically, the minerals had to be separated.

As this could not be accomplished chemically, the mechanical method of pulverization and subsequent separation by means of Klein's heavy solution was employed. The two pyroxenes were at length separated from one another, and the granules, examined under the microscope, presented some very interesting features. The pleochroic hypersthene grains were irregularly contoured, showing ill-defined cleavage, whilst the non-pleochroic diallage granules exhibited regular well-marked outlines and faces, caused by perfect cleavage or parting $\parallel \infty \text{P} \infty (100)$, $\infty \text{P} \infty (010)$, and less well-defined $\parallel \text{OP} (001)$: (Plate I, Figs. 2 and 3). The majority of the grains lay on the orthopinacoidal face, $\infty \text{P} \infty (100)$, as represented in Fig. 2, with straight extinction, and containing bands of interlaminated foreign pleochroic hypersthene, interbedded $\parallel \text{OP} (001)$, and normal to the vertical axis (c), whilst a few other grains lay on the clinopinacoidal face, as depicted in Fig. 3, giving an extinction angle of about 45° , and containing foreign hypersthene lamellæ lying inclined to the vertical axis (c), at an angle of about 16° . The specific gravities of the separated minerals could not be determined with accuracy in the warm concentrated heavy solution, because of the fluctuating values at varying temperatures. Accordingly the determinations were effected by means of the pycnometer. The specific gravities were found to be:—

Hypersthene	...	...	...	...	3.5
Diallage	...	...	...	...	3.36
Felspar	...	...	...	slightly	> 2.7
Rock itself	...	...	...	...	3.01

It was thus possible to calculate the approximate proportions of the pyroxenes and felspar in this rock:—

	Medium spec. gravity.	% by weight.	% by volume.
Felspar	2.7	55	61
Pyroxenic constituents ...	3.43	45	39
Rock itself	3.01	100	100

The two pyroxenes were present in almost equal proportions.

The strongly pleochroic hypersthene forms irregularly contoured individuals of various sizes, strongly contrasted from the diallage by (1) its intense pleochroism; (2) the higher polarization colours; (3) the absence of well-marked cleavage or parting-planes; (4) the scarcity of black needle-like inclusions so marked and numerous in the diallage; (5) the fewer but larger and more irregularly arranged intergrowths, or interlamellations of the foreign pyroxene; (6) the total absence of the twinning after the orthopinacoid; and (7) the lack of the herring-bone structure of the diallage to which the above-mentioned twinning

gives rise. However, in many individuals a well-marked striation, $\parallel \infty \check{P} \infty (010)$ and $OP (001)$, is present, and an imperfect cleavage after the prism $\infty P (110)$, while very imperfect cleavage is sometimes seen on macropinacoidal sections. The absence of well-defined crystallographic contours renders the optical investigation rather difficult. As already noted, the hypersthene is intimately and mutually interlocked with the diallage, the intruding plates of diallage being much thicker, though less numerous, than the corresponding plates of intergrown hypersthene in the diallage. A remarkable feature of the intergrowths is that many are somewhat bottle-shaped, possessing a narrow neck, through which the matter of the one has evidently been partially pressed into or else expelled from the other during solidification (Figs. 4, 15-18: Plates I, III, and IV). The most common intergrowths of diallage lie parallel to the basis $OP (001)$, whilst a second set of smaller and thinner lamellæ branch off in a vertical direction parallel to the brachypinacoid $\infty \check{P} \infty (010)$, various sections therefore giving this mineral a very characteristic interlarded appearance (Fig. 4). The pleochroism is very strong, a and c being sea-green, whilst b shows a lively hyacinth-red colour. The two intergrown pyroxenes appear to lie, as usual, with their vertical axes parallel. In a great many cases the hypersthene is wholly imbedded in the non-pleochroic diallage, forming the nucleus of the pyroxene mass. No glass or fluid lacunæ are to be observed in this pyroxene, and but few black acicular needles are present.

The isolated hypersthene was analyzed, giving the following values under I:—

		I.		II.
Si O ₂	...	51·64 %	...	53·53 %
Ti O ₂	...	0·34 %	...	—
Al ₂ O ₃	...	1·32 %	...	3·12 %
Fe ₂ O ₃	...	4·41 %	...	5·09 %
Fe O	...	18·62 %	...	13·54 %
Mg O	...	14·74 %	...	18·77 %
Ca O	...	6·46 %	...	6·19 %
H ₂ O	...	1·50 %	...	—
Na ₂ O	...	—	...	0·57 %
K ₂ O	...	—	...	0·20 %
Total	...	99·03 %	...	101·01 %
Specific gravity		3·50	...	3·31

I = analysis of separated hypersthene.

II = Dahms' analysis¹ of "pleochroic diallage" from the Zwaartkoppies "Gabbro," Hex River.

From analysis I the following table was calculated:—

¹ Loc. cit., p. 95.

	Mg	Ca	Fe ^{II}	Fe ^{III}	Al	Si	O
% of elements ...	8·81	4·61	14·48	3·08	0·70	24·09	41·36
Atomic quotient	0·3683	0·1152	0·2586	0·0551	0·0259	0·8600	2·585

The subjoined proportions were obtained from these numbers :—

$$\begin{aligned}
 R : Si &= 1 : 1 \\
 RO : R_2O_3 &= 9 : 1 \\
 Mg : (Fe^{II} + Ca) &= 1 : 1 \\
 Fe^{II} : Ca &= 2 : 1 \\
 (Fe^{II} + Fe^{III}) : Ca &= 3 : 1 \\
 (Mg + Fe^{II} + Fe^{III}) : Ca &= 6 : 1
 \end{aligned}$$

If one seek to ascertain the various proportions of the various silicates which compose this mineral, and take for this purpose the most common pyroxene-forming silicates, e.g., $MgO \cdot SiO_2$, $CaO \cdot SiO_2$, $FeO \cdot SiO_2$, and $(MgFe)O \cdot (AlFe)_2O_3 \cdot SiO_2$, it is found that there remains an excess of SiO_2 in this mineral composition of about 7·07%. Therefore some of the component silicates must be present in multiples of the above-named compounds, such as $MgO \cdot Fe_2O_3 \cdot 4SiO_2$, and $MgO \cdot Al_2O_3 \cdot 4SiO_2$, or analogous compounds. Doelter¹ affirms the existence of such polysilicates in the pyroxenes; and Dahms² asserts their presence in the constitution of the "pleochroic diallage" of the Zwaartkoppies "Gabbro," from the Hex River, near Rustenburg, as forming some of the component isomorphous compounds. If these multisilicates be used in the calculation, very satisfactory results are obtained, as follows :—

	MgO	CaO	FeO	Fe ₂ O ₃	Al ₂ O ₃	SiO ₂		%
Atomic quotient	0·3685	0·1154	0·2586	0·0276	0·0129	0·8607		
$MgO \cdot SiO_2$...	0·3280	—	—	—	—	0·3280	0·6560	39·648
$FeO \cdot SiO_2$...	—	—	0·2586	—	—	0·2586	0·5172	31·402
$CaO \cdot SiO_2$...	—	0·1154	—	—	—	0·1154	0·2308	14·015
$MgO \cdot Fe_2O_3 \cdot 4SiO_2$	0·0276	—	—	0·0276	—	0·1104	0·1656	10·054
$MgO \cdot Al_2O_3 \cdot 4SiO_2$	0·0129	—	—	—	0·0129	0·0516	0·0774	4·700
						0·8640	1·6470	99·82

Deficiency of $SiO_2 = 0·0033$.

¹ C. Doelter, "Ueber die Constitution der Pyroxengruppe": *Tschermak's Mineralog. und Petrogr. Mittheilungen*, Band ii (1880), p. 193.

² Loc. cit., p. 95.

The TiO_2 of the analysis has not been used in this table, but acts as a substitute for SiO_2 , thus making up the apparent deficiency of the latter.

Taking the results of this analysis as a whole, it is seen that they do not represent the typical composition of either a normal rhombic or monoclinic pyroxene, the lime percentage being too high and the magnesia too low for a typical rhombic pyroxene; on the other hand, there is by far not enough lime or alumina, and too much iron present for a normal monoclinic pyroxene. The analysis is decidedly that of a rhombic rather than of a monoclinic pyroxene. Dahms has made an analysis¹ of this pleochroic pyroxene, which he terms "diallage," from the "gabbros" of another part of the Zwaartkoppies (Hex River, near Rustenburg), which is notable for its disagreement with the usual monoclinic pyroxene analyses, as seen when compared with the hundreds of analyses given in Hintze's "Handbuch der Mineralogie."² Compared with Dahms' analysis this contains over 5% more FeO , with 4% less MgO , and somewhat smaller quantities of Al_2O_3 , Fe_2O_3 , and SiO_2 , the amounts of lime being about equal. Whilst Dahms' analysis thus stands abnormal to those of the usual monoclinic pyroxenes, as he himself remarks,³ yet it is very similar to those made of the pleochroic pyroxenes (hypersthene) from the various norites, taken also from the Hex River and other parts of the Zwaartkoppies, examined by the author and treated of in these and the following pages, the analyses of which, apart from optical characteristics, would mark the pleochroic pyroxenes as rhombic pyroxenes or hypersthene.

If it be also remembered that the pleochroic and non-pleochroic pyroxenes were often intimately interlocked with each other in the rock, it will be seen that each separated pyroxene is rendered more or less impure by the presence of the intergrown lamellæ of the other. Thus it is probable that the normal and homogeneous hypersthene of this rock contains even more iron and still less lime than is given in the analysis, whilst the absolutely pure diallage possesses, in all likelihood, more lime and less iron than the analysis shows, for this proves it to contain a very much higher percentage of lime and a smaller quantity of iron than the hypersthene.

The diallage is of a greyish-green colour, easily distinguishable from the feldspathic aggregate by its coloration and higher refraction, and from the hypersthene by its total lack of pleochroism in thin section. In thick isolated granules, however, a slight pleochroism is noticeable, from yellowish-green to greyish-green. It forms no automorphic individuals, but is principally grouped around the hypersthene nucleus as a girdle, or else is seen as variously shaped grains between the feldspars or as aggregates. The striking features of this diallage are

¹ See ante, p. 14, analysis II.

² Loc. cit., pp. 1,097-1,113.

³ Loc. cit., p. 94.

(1) the very pronounced striation parallel to the pinacoids OP (001) and ∞P (100), appearing almost identical with the typical diallage parting, or pseudo-cleavage; (2) the almost macroscopic to sub-microscopic intergrowth of hypersthene along two pinacoidal planes; and (3) countless short, dark, hair-like, and acicular inclusions lying in parallel rows in definite planes. The real cleavage does not appear very distinct in the pinacoidal sections because of the dark-lined striation, but on basal sections a fairly perfect cleavage is observed parallel to ∞P (110), an imperfect $\parallel \infty P$ (010), and exhibiting also the above-mentioned strong parting $\parallel \infty P$ (100). Twinning $\parallel \infty P$ (100) is very common, nearly every individual in the section being thus twinned, whilst apparent indications of polysynthetic twinning after an orthodome are abundant. At first sight, under $\times$ nicols, the intergrowths parallel to OP give one the exact impression of a multiple twinning after that plane. The single twinning $\parallel \infty P$ (100) causes a very pronounced "herring-bone" structure by the combination with the striation $\parallel OP$ (001), and with the interlamellated intergrowths after this plane (Plate III, Fig. 13), in other cases by means of the polysynthetic twinning bands (Plate III, Fig. 14). The extinction angle in the $OP \mid \infty P$ zone gave values up to 46° , whilst the intergrowths and striæ $\parallel OP$ (001) formed an angle of about 16° with the vertical axis (c). The very numerous rod-like needles in the substance of this pyroxene lie principally parallel to one plane, OP (001), and also in directions parallel to the three axes of crystallization, either occurring scattered and singly or, more commonly, in rows parallel to each other. The quantity of included needles lying in parallel rows is sometimes so great, that their presence renders the mineral quite dark, and gives the appearance of long parallel ranks, as of soldiers, or like rows of corn in a field, with definite intervals between the rows. The rods are generally of almost equal size, of about 0.035 mm. in length, but vary from very short rectangular forms to long sharp needles attaining a length of 0.2 mm., and have as a rule a square cross section. At their sharp, thin ends, the needles appear to be somewhat translucent, transmitting a reddish light, and exhibiting a very high refraction. These latter characters and the square sections indicate that these inclusions are rutile. In any case they cannot be regarded as lamellæ of ilmenite. The diallage has a sp. gr. of 3.363; it contains no glass, gas, or liquid lacunæ.

As already observed, the oft-described "herring-bone" structure is of frequent occurrence in this diallage. This phenomenon was also observed by Molengraaff in the quartz-amphibole-gabbro of Mooi River, Southern Transvaal, and the Rhenosterkop in the Orange Free State;¹ also by Teall in the Whin Sill gabbro,² and by Harker in the gabbros of Carrock Fell.³ According to these authors, however, the striation

¹ Neues Jahrb. für Mineralogie, etc., Beil. Band ix (1894), p. 287.

² J. J. H. Teall, "On the Chemical and Microscopical Characters of the Whin Sill": Quart. Journ. Geol. Soc., vol. xl (1884), pp. 647 and 650, pl. xxxix, fig. 12.

³ A. Harker, "Carrock Fell: a Study in the Variation of Igneous Rock Masses": Quart. Journ. Geol. Soc., vol. L (1894), p. 317, pl. xvii, fig. 1.

parallel to the basis OP (001) was caused by the leaf- or plate-like structure of the mineral parallel to this plane, or by polysynthetic twinning, while in this case it is caused by the intergrowth of the hypersthene parallel to the basis, the interlamellated plates of the hypersthene being of submicroscopic thinness, represented under the microscope by thin dark lines. Teall remarks (loc. cit., p. 650) that Rosenbusch suggested this explanation for the striation $\parallel$ OP (001) in the Whin Sill augite. The foregoing investigations prove that this supposition is very probably correct.

That rhombic pyroxenes are frequently intergrown with diallage $\parallel$ vertical axis (c), was demonstrated so far back as 1878 by Paul Trippke,¹ and since then, intergrowths $\parallel$ OP (001), as well as $\parallel c$, have been described by various authors. In this case the large *mutual* intergrowth is the remarkable feature.

This large, distinct mutual intergrowth of the rhombic and monoclinic pyroxenes, is very characteristic of this local gabbro-like type of the norite, for nearly all of the pyroxene individuals show this phenomenon in a most unusual degree of perfection. Fig. 4, Plate I, and Figs. 15 and 17, Plates III and IV, show the two distinct individuals of hypersthene and diallage mutually interlocked or dovetailed with each other, giving in the thin section the appearance of two hands with interlocked fingers; whilst at other times only the one or the other pyroxene sends finger-like offshoots into the other (Figs. 16 and 18). The mutually implicated tabulæ of these two minerals vary from thick plates of almost macroscopic dimensions to leaves of submicroscopic fineness, the latter being only represented by thin dark lines even under the strongest magnifying power, and which may thus be easily mistaken for cleavage traces. The thick plates are easily determined under the microscope with a low power as the one or the other of the pyroxenes, by the presence or absence of pleochroism; but the mutual intergrowth of both minerals becomes at times so closely intimate in some individuals, that it becomes almost impossible to distinguish the one from the other, or to determine which is the bearer of the other, for the whole individual participates in the strong pleochroism of the hypersthene, appearing as a homogeneous pleochroic body. Only under $\times$ nicols is such an individual seen to be composed of lamellæ of the two pyroxenes, which differ somewhat in the degree of their tints of chromatic polarization and direction of extinction.

The diallage is much more interlarded, or intergrown with the hypersthene, than, conversely, is the hypersthene with diallage. The following may perhaps be suggested as possible explanations of this phenomenon:—

¹ Paul Trippke, "Beiträge zur Kenntniss der Schlesischen Basalte und ihrer Mineralien": Inaugural Dissertation, Breslau, 1878, p. 21. "Über das Enstatit aus dem Olivinknollen des Gröditzberges."

(a) The evident tendency of the diallage to parting parallel to different pinacoidal planes may have been evinced during the period of consolidation of the two pyroxenes, thus affording more easily accessible channels for the intrusion of the still molten hypersthene material than, conversely, the hypersthene offers to the molten diallage.

(b) Or, it is possible that after the first consolidation of minerals (the felspars) there remained a residual magma, containing in solution an intimate mixture of the various isomorphous compounds, which combine in different proportions to compose the several pyroxenes. During the process of separation and expulsion of the more basic, less mobile, and somewhat earlier crystallizing hypersthene substance from the less basic, diallagic, magmatic matter, and, conversely, of the less basic from the more basic, the one solidifying mineral would retain traces and veins of the other in its own mass, especially along the planes of the least cohesion, i.e. the pinacoidal planes. It is also to be expected that of the two solidifying minerals the earlier crystallizing and less mobile mineral matter (hypersthene), possessing a higher melting-point and specific gravity, would retain a smaller quantity of the other more mobile, later-crystallizing substance (diallage); while the more viscous material of the hypersthene would not be so easily expelled from the more mobile and lighter diallagic matter. The narrow necks or outlets of the enclosed material in each mineral may be perhaps explained by the forces of crystallization, the included material being sometimes completely cut off from its own mineral mass, and enclosed in the foreign material by the closure of the outlet.

An analysis of this diallage gave the following results :—

Si O ₂	...	...	...	...	52.54 %
Ti O ₂	...	...	...	...	0.21 %
Al ₂ O ₃	...	...	...	...	0.24 %
Fe ₂ O ₃	...	...	...	...	5.12 %
Fe O	...	...	...	...	12.46 %
Ca O	...	...	...	...	17.12 %
Mg O	...	...	...	...	12.02 %
Total	...	...	...	...	99.71 %
Specific gravity	...	...	...	...	3.36

From these quantities the following table was calculated :—

	Ca	Mg	Fe ^{II}	Fe ^{III}	Al	Si	%
% of elements ...	12.230	7.212	9.690	3.584	0.127	24.540	42.117
Atomic quotient	0.306	0.3005	0.173	0.064	0.005	0.876	2.632

and from these numbers the following values :—

$$R : Si = 1 : 1$$

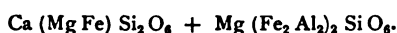
$$R_2O_3 : RO = 1 : 11$$

$$Ca : Mg = 1 : 1$$

$$Ca : (Mg + Fe^{II}) = 1 : 1.5$$

$$Ca : (Mg + Fe^{II} + Fe^{III}) = 1 : 1.8$$

The general formula is—



The same method as previously is used to determine the proportions of isomorphous compounds in this mineral:—

	Ca O	Mg O	Fe O	Fe ₂ O ₃	Al ₂ O ₃	Si O ₂		%
Atomic quotient	0.3057	0.3005	0.1730	0.0320	0.0023	0.8792		
Ca O · Si O ₂ ...	0.3057	—	—	—	—	0.3057	0.6114	36.058
Mg O · Si O ₂ ...	—	0.2662	—	—	—	0.2662	0.5324	31.390
Fe O · Si O ₂ ...	—	—	0.1730	—	—	0.1730	0.3460	20.406
Mg O · Fe ₂ O ₃ · 4 Si O ₂	—	0.0320	—	0.0320	—	0.1280	0.1920	11.323
Mg O · Al ₂ O ₃ · 4 Si O ₂	—	0.0023	—	—	0.0023	0.0092	0.0138	0.813
						0.8821	1.6956	99.990

Deficiency of Si O₂ = 0.0029

A comparison of the analyses of the hypersthene and diallage shows that they differ considerably in chemical composition, e.g., the diallage contains about 6% Fe O, a little Fe₂ O₃, and 2.7% Mg O less than the hypersthene, but 10.66% more Ca O. Compared with analyses of the various monoclinic pyroxenes heretofore reported, it appears that this mineral approaches more towards the direction of the typical diallages, because of its high percentage of lime and poverty in alumina, but contains an unusually large amount of iron, the explanation of which has been suggested on p. 16. It approaches the composition of the diallage from Malencothal, Veltlin, analyzed by Cossa.¹

The pale-green, almost colourless, salite-like pyroxene, present as small xenomorphic rounded grains of various irregular shapes, generally lies close beside the other pyroxenes, and is at times distinguishable from the felspar only through its higher refraction, intense tints of chromatic polarization, and absence of polysynthetic twinning. It shows but indistinct traces of cleavage, but some individuals exhibit single twinning. As it was present in such minimal quantity, it was impossible to separate the mineral for analysis. The salite appears

¹ Groth's Zeitschrift, vii, p. 629.

to have crystallized last of the rock constituents. It is not impossible that a norite or gabbro may be found in this district, containing a large amount of salite, representing an extreme modification of magmatic differentiation, as the Hex River norite¹ and Marico gabbro² form the other extremes. This occurrence reminds one of the presence of colourless pyroxene (salite) in varying quantities in the Whin Sill diabase,³ also of the so-called "salite-diabases" of Sweden,⁴ Rio de Janeiro,⁵ and Connecticut.⁶

The crystallization of the pyroxenes has probably taken place in the order of basicity, the most basic crystallizing first, as usual:—

- (1) Strongly pleochroic hypersthene
(much Fe and Mg, little Ca).
↓
- (2) Non-pleochroic diallage (light-coloured)
(less Fe, more Ca).
↓
- (3) Colourless, or pale-green pyroxene (salite)
(poor in Fe, much Ca).

Neither Cohen nor Dahms have noted the presence of the intergrown hypersthene and diallage, or of the three pyroxenes in the norites towards the east end of the Zwaartkoppies, which appears to be, from a petrographical standpoint, a very interesting occurrence. Cohen and Dahms only say that the "gabbros" change, towards the east end of the hills, into a more diabasic rock, with normal augite as well as diallage. Perhaps this rock under discussion is what is referred to by them.

The hornblende, doubtless of primary character, is green and strongly pleochroic. It is rare, and occurs as solitary grains here and there in the rock, almost exclusively imbedded in the hypersthene.

The iron-ores, chiefly magnetite, are very meagrely represented, occurring in small isolated grains, imbedded in the pyroxenes, as a rule, but also in the felspar. These iron-ores are, in places, decomposed to brown iron-ore, causing brown stains along fissures.

No quartz or micropegmatite is present in the sections examined.

It would appear that the primary crystallization of the basic felspar, rich in lime and alumina, extracted from the magma the greater part of those compounds necessary to form minerals with a high percentage of lime and alumina, e.g., hornblende, diallage, and salite, thus rendering the formation of these minerals relatively difficult and rare. This will

¹ See p. 24.

² Molengraaff, loc. cit., p. 220.

³ J. J. H. Teall, loc. cit., pp. 644 and 653.

⁴ E. O. Hovey, "Ueber Gang-diabase der Gegend von Rio de Janeiro, und über Salit von Sala in Schweden": *Tschermak's Mineralog. und Petrogr. Mittheilungen*, Band xiii (1892), p. 213.

⁵ Ibid.

⁶ W. M. Davis and C. Livy Whittle, "Diabases of Connecticut Valley": *Bull. Mus. Comp. Zoology, Harvard College, Cambridge, U.S.*, vol. vii, No. 9, 1883, and 1889.

explain the poverty of the pyroxenes in alumina and lime, and the preponderance of the hypersthene constituent, which requires but little lime in its composition.

This diallage-norite may also be termed a "hypersthene-diallage-gabbro," as Cohen has named the gabbro of Setigalanga, in Lydenburg,¹ because of the high percentage of diallage it contains, if considered as a geologically independent mass of rock; but if it be only regarded as a local modification or facies of the normal hypersthene-norite of the western end of the Zwaartkoppies, it must be called a diallage-norite. It evidently forms the connecting link between the norites and the gabbros.

Many points of similarity may be observed between this rock and the Lydenburg hypersthene-diallage-gabbro described by Cohen. In both rocks the proportions of the two fresh pyroxenes are about equal; the hypersthene appears to lie parallel throughout the rock mass, the pyroxenes possess similar inclusions and degrees of pleochroism, and often the hypersthene is completely imbedded in the diallage.

(ii) *Diallage-Norite from the Zwaartkoppies, about 25 miles N.N.W. of Pretoria.*

The macroscopic and microscopic characters of this rock are practically the same as in the previous norite, the same mineral constituents being present, with the exception of biotite, a few folia of which occur here and there throughout this rock. Here, however, a typical granitoid structure is developed, unlike the former rock, which is somewhat schistose in appearance. The plagioclase, as usual, predominates, whilst the diallage distinctly recedes before the hypersthene, and the colourless to pale-green, salite-like pyroxene and the hornblende are present in small, and about equal, quantities. Frequently the diallage grows around the hypersthene, as the shell of a nut encloses its kernel (Fig. 19, Plate IV); at other times a girdle of hornblende takes the place of the diallage around the hypersthene, or else encloses the diallage which already contains a nucleus of hypersthene, thus causing a concentric arrangement. Yet all these several encirclings of minerals are certainly of primary nature, crystallized in the order of the increasing percentage of alumina. Besides solidifying around the hypersthene individuals, the diallage has also served as interstitial material for the spaces between the felspar individuals. It thus presents angular, irregularly bounded, wedge-like forms, in thin section. The hypersthene, on the contrary, forms large independent individuals up to 5 mm. in length. The mutual intergrowth of hypersthene and diallage is here seldom developed, or is submicroscopic. The proportions of felspar to the pyroxenes were approximately as follows:—

¹ E. Cohen, Erläut. Bemerkungen, etc. (see ante, p. 7).

	% by weight.	% by volume.
Felspar	68	72
All pyroxenes ...	32	28
	100 %	100 %

Specific gravity of rock = 2·87.

Only the hypersthene could be separated for analysis, for it is present as large pure individuals, while the diallage exists in too small particles for effective separation. An analysis of the hypersthene gave the following results:—

Si O ₂	54·49 %
Fe ₂ O ₃	21·84 %
Al ₂ O ₃	traces
Ca O	4·40 %
Mg O	19·21 %
Total	99·94 %
Specific gravity ...	3·38 %

Unfortunately, the whole of the iron was determined as Fe₂ O₃ by mistake, and as no more material was at disposal a second analysis could not be made. Thus, a complete chemical comparison cannot be made between this and the other pyroxene analyses. From the above numbers these values are calculated, the fact that all the iron was determined as Fe₂ O₃ having but little influence on the percentage of that element:—

Elements.	Fe	Mg	Ca	Si	O
% of elements ...	15·28	11·52	3·14	25·43	44·57
Atomic quotient ...	0·2728	0·4800	0·0785	0·9085	2·7856

and herefrom the following proportions:—

$$\begin{aligned} R : Si &= 1 : 1 \\ Mg : Fe &= 1·8 : 1 \\ Mg : Ca &= 6 : 1 \\ Fe : Ca &= 3·5 : 1 \end{aligned}$$

This analysis is, therefore, very similar to that of the hypersthene of the preceding norite, and also closely resembles that of Dahms' pleochroic "diallage." Compared with the former hypersthene it is 2% poorer in lime, but 4·5% richer in magnesia, whilst the quantity of iron in both minerals is about equal. The smaller quantity of lime in this case,

where the hypersthene is much purer, being far less intergrown with the diallage, appears to prove, what was already indicated on p. 16, that the normal hypersthene of the preceding rock contains less lime than given in its analysis, the increase being due to the intergrown diallage, which is rich in lime.

No intergrowths between the salite-like pyroxene and the other pyroxenes were seen, but the former is often encircled and associated with the green hornblende. Fig. 20, Plate IV, shows the association of the hypersthene, diallage, hornblende, and salite.

The primary green hornblende is strongly pleochroic, from pale yellowish-green to deep blue-green. The extinction angle as measured on isolated granules under the microscope, as well as in thin section, gave values of about 15° .

A little uraltite is also present as a decomposition product of the hypersthene.

The felspar consists of somewhat clouded plagioclase, with high extinction, and a specific gravity of over 2.7, and belongs principally to the anorthite end of the lime-soda series. It exhibits a great tendency towards double twinning, after the albite and pericline laws, and a few individuals show a remarkable combination of double twinning after the Carlsbad and the equivalent of the monoclinic Manebach laws, as seen in Fig. 5, Plate I. A good deal of specifically lighter and lower-extinguishing plagioclase is also present, but much less in quantity than the anorthite.

(iii) *Hypersthene-Norite from the Hex River, near Rustenburg, at the west end of the Zwaartkoppies.*

This rock, according to Hübner,¹ who collected the hand-specimen examined, occurs as large intrusive sheets or sills, and apparently forms the chief rock of the Rustenburg plateau, as well as of the "greenstone" hills (the Zwaartkoppies) to the east, north-east, and south-east of the town of Rustenburg. It appears to be identical with the "gabbro" described by Dahms,² and collected by Cohen in this vicinity, as well as with the specimen of hypersthene-norite or gabbro mentioned by Hatch³ as occurring 8 miles north of Rustenburg. The probability is that it belongs to the same eruptive magma, or eruption, as the "gabbros" of the Zwaartkoppies range, extending from Rustenburg almost to Pretoria.

In outward appearance it is a typical norite, or gabbro, presenting much the same features as the last-described norite. Automorphic crystals of pyroxene may be observed. The rock possesses a granitoid structure, but many of the pyroxene crystals appear to be roughly automorphic, having several crystal edges well developed. The constituent minerals are (1) felspar, (2) strongly pleochroic hypersthene,

¹ Ad. Hübner, "Geognost. Skizzen," etc. : Petermann's Mittheilungen, 1872, p. 422.

² Loc. cit., p. 91.

³ F. H. Hatch, "A Geological Survey of the Witwatersrand," etc. : Quart. Journ. Geol. Soc., vol. liv (1898), p. 76.

with (3) a very little iron-ore, the felspar and pyroxene being present in about equal quantities. Here, again, has the felspar crystallized partly before, though principally contemporaneously with the pyroxene, since the latter contains many inclusions of felspars.

On disintegrating the rock preparatory to the separation, a number of the large hypersthene individuals were detached unbroken from the matrix, which on examination proved to be well-formed but rough automorphic rhombic crystals, up to 5 mm. in length. The faces were very uneven and rough, but the following well-developed forms could be identified—large $\infty \bar{P} \infty (100)$ (*a*), small $\infty \check{P} \infty (010)$ (*b*), and $\infty P (110)$ (*m*); but the terminal facets were too rough to be recognized (see Fig. 6, Plate I). The obtuse prismatic angle lies in front of the crystal, and the acute one on the right and left sides.

The following tabulated proportions of the felspar and pyroxene were determined approximately from the specific gravities :—

	Specific gravity.	% by weight.	% by volume.
Felspar	2.71	55	60
Hypersthene	3.36	45	40
Rock itself	2.93	100	100

The felspathic constituent possesses no new features, but is practically the same as that of the other norites described.

The fresh pleochroic hypersthene differs only from that already described in the other norites, in that it is intergrown with numerous small colourless included plates of a mineral which is held to be plagioclase by the author, and which lie parallel to the vertical pinacoids. In ordinary light these are hardly to be distinguished from the light-coloured hypersthene substance, but under $\times$ nicols they appear clearly defined in the hypersthene, through the differences in polarization tints and extinction (Fig. 25, Plate V). So far as can be seen, no mutual intergrowth between hypersthene and plagioclase exists, as is the case between hypersthene and diallage. Here an interlarding of thin incipient felspathic individuals, parallel to the brachypinacoid principally, has evidently taken place contemporaneously with the crystallization and consolidation of the pyroxene. This will partly account for the high lime percentage in this mineral. A fine striation is seen on basal and macropinacoidal sections, running $\parallel \infty \check{P} \infty (010)$, representing, perhaps, a submicroscopic lamellated combination with some other mineral along that plane. In the macropinacoidal sections appear numerous parallel bands as of polysynthetic twinning, faintly delineated yet distinct, lying $\parallel \check{P} \infty (011)$. This phenomenon represents probably a polysynthetic twinning after the brachydoma, for on basal sections the bands are seen lying $\parallel \infty \check{P} \infty (010)$.

The isolated material of the hypersthene was very pure, for the large homogeneous hypersthene individuals had only to be separated from the light plagioclase. An analysis gave the following results:—

Si O ₂	...	...	...	...	...	50·28 %
Ti O ₂	...	...	...	...	...	0·24 %
Al ₂ O ₃	...	...	...	...	...	1·49 %
Fe ₂ O ₃	...	...	...	...	...	9·79 %
Fe O	...	..	...	...	...	7·82 %
Mg O	...	...	...	...	...	23·00 %
Ca O	...	...	...	...	...	7·33 %
H ₂ O	...	...	...	...	...	0·16 %
Total	...	..				100·11 %
Specific gravity	...					3·36

The following table was calculated from the above values:—

	Mg	Ca	Fe ^{II}	Fe ^{III}	Al	Si	O
% of elements ...	13·800	5·236	6·082	6·840	0·883	24·464	43·386
Atomic quotient	0·5750	0·1309	0·1086	0·1221	0·0327	0·8737	2·7116

and herefrom the subjoined proportions:—

R : Si = 1 : 1
R₂ O₃ : RO = 1 : 5·2
Fe^{II} : Mg = 1 : 5·3
(Fe^{II} + Fe^{III}) : Mg = 1 : 2·5
Ca : Mg = 1 : 4
Ca : (Mg + Fe^{II}) = 1 : 5

The following proportions of isomorphic compounds combining to form the hypersthene were found:—

	Mg O	Ca O	Fe O	Fe ₂ O ₃	Al ₂ O ₃	Si O ₂		%
Atomic quotient	0·5750	0·1309	0·1086	0·0611	0·0146	0·8420		
Mg O · Si O ₂ ...	0·4993	—	—	—	—	0·4993	0·9986	57·112
Fe O · Si O ₂ ...	—	—	0·1086	—	—	0·1086	0·2172	12·422
Ca O · Si O ₂ ...	—	0·1309	—	—	—	0·1309	0·2618	14·973
Mg O · Fe ₂ O ₃ · Si O ₂	0·0611	—	—	0·0611	—	0·0611	0·1833	10·483
Mg O · Al ₂ O ₃ · 4 Si O ₂	0·0146	—	—	—	0·0146	0·0584	0·0876	5·010
						0·8583	1·7486	100·00

Deficiency of Si O₂ = 0·0163

This is certainly a hypersthene analysis, but, like the previous hypersthene, contains an abnormally large amount of lime. Again, the amount of ferrous oxide (FeO) is small, while that of the ferric oxide (Fe_2O_3) is unusually large. However, in its general composition, this pyroxene strongly resembles the previous hypersthene of the norites from the east end of the Zwaartkoppies, as well as Dahms' "diallage"¹ from the "gabbro" of the same neighbourhood as the present rock. Dahms noted that his "diallage" was very free from inclusions, and yet his analysis shows a high percentage, over 6%, of lime, and it is remarkable that the three hypersthene treated of in this paper contain also a large amount of lime. Although a good deal of this excess of lime may be explained, in the one case, by the numerous feldspathic inclusions, and in the others by the numerous intergrowths of a monoclinic lime-pyroxene (diallage), yet taking Dahms' results into consideration, and remembering that the whole of the lime may not be thus accounted for, it is evident that, in these Transvaal norites we have to do with hypersthene which are unusually rich in lime.

In reviewing the results obtained from the foregoing investigations, it would seem that the term "*norite*" can be applied to these rocks instead of the name "*gabbro*," used by Cohen and Dahms, since the principal pyroxenic constituent is the strongly pleochroic pyroxene, which in these rocks has all the characteristics of rhombic hypersthene.

Hübner also mentions a similar occurrence of this rock in Bechuana-land, at Schoshong.

THE MARICO ROCKS.

In the Marico District, one day's journey, about twenty miles north-west of Sephton, Hübner collected, in 1868, three very interesting specimens of gabbro and norite, apparently showing the gradation of a normal, medium-crystalline, quartzless gabbro into a microcrystalline, fine-grained hornstone. These specimens were probably taken from a gabbro near a contact with some sedimentary beds of the Magaliesberg series, although Hübner does not mention anything in this connection. The first specimen is a

(iv) *Hypersthene-Diallage-Gabbro*.

It is a very fresh, medium-grained, holocrystalline rock, consisting of dark pyroxene with metalloid lustre and a colourless plagioclase, together forming a typical ophitic structure, the well-developed plagioclase individuals penetrating far into the xenomorphic pyroxene grains. (Figs. 21 and 22, Plate V.) The essential constituent minerals are—(1) plagioclase, (2) diallage, (3) hypersthene with (4) some green hornblende, (5) a few grains of iron-ore, and (6) leaves of biotite here and there. The plagioclase crystallized before the diallage, and the latter before the hypersthene. The hypersthene thus has its position

¹ See ante, p. 14.

reversed, with regard to the diallage, compared with the relations of the pyroxenes in the other norites already described, since in this case it does not form the nucleus for the diallage to grow around, but takes its position on the outside of the diallage grains.

The plagioclase forms by far the largest proportion of the rock, whilst the quantity of diallage much exceeds that of the hypersthene. The specific gravity of the rock is 2.8.

The felspar, forming water-clear, fresh, automorphic crystals, is a high-extinguishing basic plagioclase, anorthite, or bytownite, as in the Zwaartkoppies norites. Besides the usual double twinning after the albite and pericline laws, individuals are frequently met with in which another combination is present, namely, that of the Bavenoer and albite laws, which presents in cross section the characteristic picture as shown in Fig. 7 on Plate II. As in the felspar of the Zwaartkoppies, glass negatives with dark enclosures of another mineral (Fig. 1, Plate I) are very frequent, and appear to lie by preference parallel to and to aggregate along the composition planes of twinning, thus reminding one of the behaviour of the rod-like or acicular inclusions in the diallage of this rock and the other norites.

The prominent characteristic of the diallage is the arrangement, or concentration, of numerous long thread-like needles of a dark mineral, into many distinct bands or beds, which lie parallel to each other at short distances, throughout the mineral mass. (Fig. 8, Plate II.) The faces of the parallelepiped in this figure do not correspond with any crystal planes, but represent possible sections of the beds as seen in the microscope. It is noteworthy that under crossed nicols, these bands or beds are identical with a seeming polysynthetic twinning in the diallage (see Fig. 22, Plate V), and appear to be interbedded after the same law as the intergrowth of the hypersthene and diallage in the Zwaartkoppies norite, i.e. after the basal plane $OP(001)$. As will be seen in Figs. 21 and 22, the enclosed fibres, or needles, are of great length, and lie approximately parallel to each other in the bands or beds, the structure and arrangement of the latter somewhat resembling the grain of an oak plank, the several fibres being thicker or thinner, longer or shorter, and often twisted like the strands of a rope. A peculiarity is that the beds do not run right to the boundaries of the diallage, but frequently disappear in the neighbourhood of the interpenetrating felspar individuals, before the line of contact of both minerals, reappearing in the diallage on the opposite side of the felspar at some distance from the boundary-line. It should be mentioned that the diallage in the hand-specimen examined appears to be only one large individual, the pyroxenic mother liquor having consolidated simultaneously in a mass, filling out the intercrystal spaces between the primarily crystallized felspars. This is proved by the fact that throughout the diallage of every section the bands and cleavage invariably lie in one direction, with simultaneous extinction of the

mineral. Thus several sections, at right angles to each other, had to be made, as in the case of a single large mineral, in order to determine the optical and physical properties. The needle beds must be regarded as primary, having been formed with the crystallization of the diallage, for the rock is of ideal freshness, quite free from traces of decomposition or of pressure phenomena, and the needles are solely confined to the pyroxenic constituent.

It is difficult to determine the nature of the mineral of which these long needles are composed. They are thought to be rutile. Magnified to 300 diameters, they are translucent, and transmit a reddish light, showing, under crossed nicols, yellow polarization tints. Being of such microscopic dimensions, it is impossible to separate the needles for chemical analysis, for the small quantity of material at disposal did not permit of a trial. Other isolated dark rods are also imbedded in the diallage, lying in a direction normal to the beds.

The other diallages already described sometimes show partial concentration of needle-like inclusions into bands or beds, but the phenomenon is not so marked as in this case. (See p. 17.)

The strongly pleochroic hypersthene differs only from that already described through its later crystallization than the diallage, as it here fills up the spaces between the diallage and felspar.

The iron-ore is generally ilmenite. Both this and the biotite are very scarce, the latter occurring only in small leaves here and there, mostly associated with the iron-ore.

(v) *Finely crystalline Quartz-Norite.*

This is a brown-coloured rock, much more compact and finer-grained than the preceding, and thus loses to a great extent the typical gabbro appearance. Colourless felspar, dark pyroxene, and dark mica can be recognized, from their colour, cleavage, and lustre, in the hand-specimen, the ingredient minerals being scattered evenly throughout the rock, and are of nearly uniform dimensions. The long lath-shaped individuals of pyroxene, up to 5 mm. in length, impart a somewhat microporphyritic character to the rock. The constituents revealed by the microscope are (1) felspar, (2) faintly pleochroic rhombic pyroxene, (3) monoclinic pyroxene (diallage), (4) quartz, (5) biotite, and (6) iron-ore. The chief constituents, felspar and pyroxene, are present in about equal quantities. The diallage is much less than the hypersthene. The biotite is very plentiful as solitary leaves or as patches, and also thickly interlarded throughout the pyroxenes. The quartz is developed both as single grains, and as a micropegmatitic intergrowth with the felspar. The constituents crystallized as follows: iron-ore, biotite, felspar, the pyroxenes, quartz, and micropegmatite.

Indications of considerable protoclastic pressure action are especially noticeable in the long pyroxene individuals, many of which are considerably bent, and lie in a mass of crushed and broken felspars, whilst

the leaflets of mica are here and there distorted, particularly those included in the pyroxenes.

The specific gravity of the rock is 2.97.

The basic plagioclasic felspar is here much twinned, the twinning lamellæ being very numerous and narrow, and clearly show the cementing of the broken pieces with neophytic felspar material. A few individuals show a decided zonary structure, which is, however, only submicroscopically developed in the majority, as shown by the centrifugally migrating extinction. Large numbers of colourless inclusions lie parallel to the pinacoids, at times imparting to the felspar a somewhat micropertthitic appearance. Long needles of apatite, leaves of biotite, and grains of iron-ore are often present as inclusions.

The fresh hypersthene is almost non-pleochroic, and chiefly forms long, lath-shaped, irregularly contoured, indented individuals, up to 5 mm. in length, sometimes bent or broken by pressure. Here and there partial automorphism is seen, the cross-sections revealing the development of small $\infty P (110)$, and large $\infty \bar{P} \infty (100)$ and $\infty \check{P} \infty (010)$ faces. Numerous leaves of biotite are interlarded parallel to the three pinacoids, the basal surfaces of the mica lying parallel to the plane of intercalation. The prismatic cleavage is perfect, often parting or pseudo-cleavage is observable parallel to $\infty \check{P} \infty (010)$, whilst the long individuals are traversed by irregular horizontal fissures, caused probably by pressure. Mutual intergrowth of the diallage and hypersthene is seldom, but, when present, is developed as large inclusions of the one mineral in the other, with the vertical axes (c) parallel, but the horizontal axes (b) lie at any angle to each other, up to 90° . (Figs. 9, 10, and 11, Plate II.)

The hypersthene was isolated for analysis, but it was impossible to separate the intimately intergrown leaves of biotite from the hypersthene substance. A faint pleochroism from yellowish-red to greyish green was observable in the isolated granules. The following are the results of the analysis:—

Si O ₂	..	...	...	...	53.35 %
Ti O ₂	...	...	...	...	0.36 %
Cr ₂ O ₃	...	...	...	...	traces
Al ₂ O ₃	...	...	...	...	4.50 %
Fe ₂ O ₃	...	...	...	...	5.12 %
Fe O	...	...	...	...	13.32 %
Ca O	...	...	...	...	4.42 %
Mg O	...	...	...	...	16.15 %
Mn O	...	...	...	...	0.67 %
K ₂ O + Na ₂ O	...	...	..	..	2.17 % (determined as K ₂ O)
H ₂ O	..	...	...	...	0.40 %
Total	...	...	...	...	100.46 %
Specific gravity	...	...	...	...	3.366

From these numbers the values in the following table are calculated :

	Mg	Ca	Fe ^{II}	Fe ^{III}	Al	Si	O
% of elements ...	9.7380	3.1570	10.3600	3.5400	2.3820	25.038	42.375
Atomic quotient	0.4008	0.0789	0.1850	0.0632	0.0882	0.8847	2.6360

from which are deducted the following approximate proportions:—

$$R : Si = 1 : 1.$$

$$Mg : Fe^{II} = 1 : 0.5.$$

$$Mg : (Fe^{II} + Fe^{III}) = 1 : 0.6.$$

$$Mg : Ca = 1 : 0.2.$$

$$R O : R_2 O_3 = 1 : 0.23.$$

The percentage of the constituent isomorphous compounds is also tabulated as subjoined:—

	Mg O	Ca O	K ₂ O	Fe O	Fe ₂ O ₃	Al ₂ O ₃	Si O ₂		%
Atomic quotient	0.4008	0.0789	0.0231	0.1850	0.0316	0.0441	0.8905	1.6531	100.00
Mg O · Si O ₂ ...	0.3482	—	—	—	—	—	0.3482	0.6964	42.070
Fe O · Si O ₂ ..	—	—	—	0.1850	—	—	0.1850	0.3700	22.353
Ca O · Si O ₂ ...	—	0.0789	—	—	—	—	0.0789	0.1578	9.533
MgO · Fe ₂ O ₃ · 4SiO ₂	0.0316	—	—	—	0.0316	—	0.1264	0.1896	11.454
MgO · Al ₂ O ₃ · 4SiO ₂	0.0210	—	—	—	—	0.0210	0.0840	0.1260	7.612
K ₂ O · Al ₂ O ₃ · 3SiO ₂	—	—	0.0231	—	—	0.0231	0.0693	0.1155	6.978
	0.4008	0.0789	0.0231	0.1850	0.0316	0.0441	0.8918	1.6553	100.00

Deficiency of Si O₂ = 0.0013

The chemical analysis of this hypersthene is therefore analagous to those of the Zwaartkoppies norites. In this case, however, the potash and alumina percentages are very high, the former being omitted from the calculation of the other analyses because of its scarcity in those hypersthene. The presence in this hypersthene of the compounds named in such comparatively large quantities may be, for the most part, accounted for by the interbedded biotite, as a glance at the foregoing table will show.

The diallage has a more marked striation, and possesses many more inclusions of biotite than the hypersthene. The numerous short cross-sections of the biotite leaves impart a brown, fibrous, serpentinized appearance to the mineral, which is, in reality, very fresh. Cohen has

also described the occurrence of biotite inclusions in the diallage of the hypersthene-diallage-gabbro near Setigalanga, Lydenburg.¹ Single twinning $\parallel \infty P \infty (100)$ is occasionally to be seen. Its parallel intergrowth with the hypersthene has already been discussed.

Throughout the rock, quartz is present, as grains, singly, or in groups, and in many parts forms beautifully intergrown micropegmatite with the felspar. The quartz and micropegmatite seem to be primary, and to have crystallized last of the rock constituents, but not deposited by later circulating solutions, for the whole rock is extremely fresh and undecomposed. The isolated individuals of quartz and felspar in the rock appear to be of earlier consolidation than those combined to form the micropegmatite.

The occurrence and origin of micropegmatite in basic rocks have been often described and discussed by petrographers, for instance, in earlier years by Michel-Lévy, Phillips, Irving, Hill and Bonney, Sollas, Teall, Kühn, and others, while lately it has been brought into prominence by the researches of Sollas,² Harker,³ Romberg,⁴ and Holland.⁵ It would here appear that Holland's theory is most applicable to explain the genesis of the micropegmatite; but in this rock no evidence is present of micro-miarolitic structure, caused by contraction during crystallization of the micropegmatite, nor of decomposition of the norite constituents around the micropegmatite patches, as is the case in the augite-diorites described by Holland from the Madras Presidency.⁶

Biotite in considerable quantity occurs as patches or solitary leaves, and shows single and multiple twinning $\parallel \infty P (110)$.

The primary nature of the apatite is indicated by its broken condition in the bent biotites and crushed felspars. Small zircon crystals are very frequent in this rock.

(vi) *Microcrystalline Norite.*

This is a very compact, dark grey-brown rock, composed of grains of microscopic size. It has the appearance of a very hard, fine-grained, dark sandstone, or metamorphic rock. Its specific gravity is 2.72.

Under the microscope, again, at the first glance, the general appearance and structure seem to be those of a typical metamorphic sedimentary rock, possessing a directionless granular structure, no mineral being automorphic, but possessing irregular rounded and indented contours. Under ordinary light a colourless groundmass is

¹ See ante, p. 7, loc. cit.

² Trans. Roy. Irish Acad., vol. xxx (1894).

³ A. Harker, "Carrock Fell: a Study in the Variation of Igneous Rocks": Quart. Journ. Geol. Soc., vol. L (1894), p. 311, and vol. li (1895), p. 133.

⁴ J. Romberg, "Petrographische Untersuchungen an Argentinischen Graniten," etc.: Neues Jahrb. für Mineralogie, etc., Beil. Band viii (1893), p. 305 seqq. Also, "Petr. Unters. an Diorit-, Gabbro-, u. Amphibolitgesteinen": Neues Jahrb. für Mineralogie, Beil. Band ix (1894-5), p. 293.

⁵ Thomas H. Holland, "Augite-Diorites with Micropegmatite in S. India": Quart. Journ. Geol. Soc., vol. liii (1897), p. 405.

⁶ Loc. cit., pp. 411, 415.

seen (Fig. 23, Plate V), in which numerous small rounded grains of pyroxene, iron-ore, and a great number of biotite leaves stand out in sharp relief. If, however, the nicols be crossed, a striking contrast to the above is seen (Fig. 24, Plate V), the colourless groundmass resolving itself into numerous small granules of different minerals, e.g. quartz and high- and low-extinguishing plagioclase. The two feldspars appear to be the predominating minerals, the much twinned plagioclase of low extinction being present in the greater quantity. Quartz is third in bulk, after which come biotite, pyroxene, and lastly, iron-ore. Very numerous apatite and zircon needles are sprinkled plentifully throughout the rock.

Noteworthy in this case is the great quantity of quartz and biotite and the recession of the pyroxene, as compared with the two preceding rocks, this rock probably representing the final stage of the norite near a contact, perhaps in a state of transition into a vitreous character. The low specific gravity is accounted for by the scarcity of pyroxene. To give an idea of the smallness of the grain, it may be stated that the largest-grained mineral present (polysynthetically twinned plagioclase) measured up to 1 mm. along the greatest dimension.

The lower-extinguishing plagioclase is the predominant and largest-sized mineral, up to 1 mm. long, and usually forms long, laterally developed, rather narrow, and irregularly indented individuals. (Fig. 24, Plate V.) Many grains possess the identical appearance of microperthite, while others plainly exhibit the polysynthetic twinning of plagioclase, the twinning lamellæ being very numerous and narrow, much as in the preceding rock, and at times almost totally disappear. Colourless inclusions, the nature of which cannot be ascertained, are very frequent, lying parallel to the pinacoids, thus giving the mineral its microperthitic appearance.

The high-extinguishing plagioclase forms the second feldspar, and occurs as small equidimensional irregular grains, much smaller than the other feldspar. It is fresh, and generally possesses only a single pair of twinning lamellæ, with an extinction angle of about 40° . The usual double twinning appears in a few individuals, but neither cleavage nor inclusions could be seen.

Besides rounded formless grains, the pleochroic rhombic pyroxene possesses partially and fully developed crystals, showing the following faces: $\infty P(110)$, $\infty \bar{P} \infty (100)$, $\infty \check{P} \infty (010)$, $\bar{P} \infty (101)$, and $OP(001)$; the prismatic faces being small, and the macro- and brachypinacoidal facets large. The maximum length is 0.2 mm. and breadth 0.13 mm., but the majority measure only about half of these dimensions, and go down to submicroscopic size.

The quartz occurs as single granules, or as grain aggregates, but is not developed as micropegmatite, as in the former rock. The grains are of very even size, and attain a length of 0.25 mm. Glass inclusions with fixed dark bubbles are very frequent.

A considerable quantity of biotite is present, as single leaves and as aggregates, most individuals being twinned either singly or polysynthetically $\parallel \infty P (110)$, and contain inclusions of apatite and iron-ore. The folia attain a breadth of 0.5 mm.

Numerous apatite needles lie imbedded in all the rock constituents, and have a maximum length of 0.21 mm. and breadth of 0.03 mm.

Possibly exceeding the number of apatites, are the colourless, short, thick needles of zircon, scattered throughout the whole rock. The maximum length and breadth are 0.06 mm. and 0.03 mm. respectively.

Small rounded grains, or six-sided crystals of black iron-ore, up to 0.18 mm. in diameter, i.e. of about the size of the pyroxenes, are sprinkled plentifully throughout the rock.

Some pulverized rock was submitted to treatment first with hydrochloric acid, and then digested with hydrofluoric acid. A residue of pellucid zircon needles, together with a number of brilliantly glancing, pink-coloured, pellucid crystals, possessing a very high refraction, remained behind, and was examined under the microscope. The latter isolated crystals evidently belong to the hexagonal system, being mostly composed of pyramidal and basal faces, and thus lie, as a rule, on the basal surface; but one or two pyramidal crystals were seen composed solely of a hexagonal pyramid, which would correspond to $\frac{1}{2}P 2$ of the ruby. This mineral is, in all probability, a *ruby*, from its colour, crystallographic and optically uniaxial characters, as well as its insolubility in hydrochloric, hydrofluoric, and concentrated sulphuric acids. For want of material this interesting occurrence could not be further investigated. In the thin sections of the rock, this ingredient could not be detected.

It would not seem improbable that the large quantity of biotite, zircon, apatite, iron-ore, and the presence of ruby, together with the extremely dense condition of the rock, are to be considered as endomorphic characters, the rock lying in peripheric position, as part of a larger mass. Whether this is indeed actually the case is a question only to be decided by further field and laboratory investigation.

(vii) *Quartz-Diallage-Norite, in contact with Magaliesberg Tuffs, forming a dyke therein.*

The norite was somewhat decomposed in the hand-specimen received, which was taken from the immediate contact.

According to Mr. Dörrfel, who discovered this occurrence, and to whom the author is indebted for the specimens, and for geological notes on the northern Marico District, this norite dyke breaks through the Magaliesberg Beds, about half-way between the Dwarsberge and Zeerust, a short distance to the west of a large overflow or sheet of pyroxenite,¹ and tilts up the flags or tuff through which it appears at the surface to

¹ See p. 38.

a high angle on each side. This causes a dip in opposite directions to the right and left of the dyke. From the rough sketch received, it appears that the Magaliesberg Beds to the immediate north-west of Zeerust dip 20° – 30° in a N.W. direction, and strike N.W.–S.E., whilst to the south of the Dwarsberge they are reported as dipping 20° S. and striking E.–W. As usual in this formation, numerous sheets and dykes of "greenstones" are met with in this district.

On macroscopic examination, the large crystalline structure at the contact first attracts the attention, the crystals of the dark pyroxenic constituents here attaining a length of 8 mm. (Fig. 12, Plate II). The plagioclase is noticeable for its want of freshness, showing no glancing cleavage faces as usual, but has a dull greenish-grey, saussurite-like appearance, with conchoidal or irregular fracture. The dark pyroxenes, however, show well-defined cleavage faces, with brassy, metalloid lustre, and fibrous appearance. The contact between the sedimentary and igneous rock is very sharply defined, there being no trace of transition or fusion of the one into the other. The metamorphosed tuff loses, at the immediate contact, as is usual, its distinct sedimentary character, and becomes a dark compact rock, noticeable principally by its richness in pyrites, which appears to have concentrated at the junction as fine grains. No macroscopic contact minerals were seen.

Under the microscope both the igneous dyke rock, as well as the tuff, show themselves to be in a very decomposed condition. Neither the pyroxenes nor the plagioclase of the former are fresh, but the further away from the immediate contact the fresher are the constituents. The structure and composition of this norite is analagous to that of the Zwaartkoppies, described on p. 22. There are the two pyroxenes, hypersthene and diallage, present, the latter encircling the nucleus of the former. Holland mentions a similar combination of pyroxenes in the dyke augite-diorites of the Madras Presidency.¹ There is also a high-extinguishing plagioclase, whilst it is interesting because of the appearance of frequent primary quartz grains. The structure is somewhat more porphyritic than granitoid, since automorphic grains of hypersthene may be observed, the other constituents being xenomorphic. The quartz crystallized last, and fills up the cavities and interstices left between the feldspars on consolidation. No definite signs of crushing action are apparent.

The plagioclase does not possess such a high extinction as that of the other gabbros, but gives values up to 30° , thus belonging to bytownite. It is rather decomposed, assuming a somewhat saussuritic appearance, but often the crystal outlines and twinning lamellæ are visible under the microscope. It sometimes gives rise to a partial ophitic structure by penetrating the diallage.

The hypersthene is similar in structure and inclusions to that of

¹ Loc. cit., p. 406.

the Zwaartkoppies norite. Single large enclosures of diallage are frequently present, and a strong striation is present on the brachypinacoidal sections, probably representing long plate-like inclusions parallel to $\infty \bar{P} \infty$ (100). The number of short, dark, rod-like inclusions here varies greatly with the decomposition of the mineral, increasing with the advance of decomposition. Much-decomposed individuals show themselves to be attacked most easily along fissures and cleavage planes, where numerous secondary grains of iron-ore are deposited, resulting from the decomposition of the highly ferruginous pyroxene into the hornblende, urallite, and chlorite, which contain less iron.

The diallage, besides encircling the hypersthene, also fills up the intercrystal spaces between the feldspars, in the same way as does the quartz. This pyroxene corresponds more to the typical diallage than any of the diallage-like augites previously described in this paper, as it shows a most perfect parting $\parallel \infty \bar{P} \infty$ (100), together with the interlamellation or parting $\parallel OP$ (001), as well as the inclusions usual in the diallages already described. Perfect prismatic and imperfect clinopinacoidal cleavage is also present; the extinction angle is high, measuring up to 45° . This diallage resists weathering or decomposition much better than the hypersthene, and is usually found in a very fresh condition around and within the more decomposed pleochroic mineral. No analysis was made of the pyroxenes of this rock, since they are too decomposed to give good results, but they will probably be of the same chemical composition as those analyzed from the previous rocks.

Small veins of calcite, due to the decomposition of the feldspar, traverse the rock in different directions, and show well-developed rhombohedral forms around the sides of the druses, with chalcedony as a centre mass.

Primary quartz, with inclusions of liquid CO_2 and sillimanite, is often met with as irregularly bounded grains serving as filling in material between the feldspar crystals. With regard to the presence of quartz in this rock, it is probable that after the building up of the basic feldspar-pyroxene framework, through crystallization of the molten rock in the dyke fissure, a residual acid, aquo-igneous mother-liquor or magma of SiO_2 remained, which crystallized in the remaining intercrystal spaces as quartz, with numerous CO_2 inclusions, and fine needles of a colourless mineral, probably sillimanite, the latter forming druses between the feldspar crystals, which formed the sides of the interstices, and also floating crystals in the hardening quartzose mass. The occurrence of quartz in this dyke norite appears to be similar to that observed by Mr. Thomas H. Holland in the augite-diorites in South India,¹ and in the dyke gabbros of Madras.² In the present case no micropegmatite

¹ "Augite-diorites with Micropegmatite in S. India": Quart. Journ. Geol. Soc., vol. liii (1897), p. 405.

² Geological Survey of India, vol. xxx (1887), pt. 1.

is formed. Harker¹ has also described a similar phenomenon in the gabbro of Carrock Fell, but he deals with a larger mass of rock. If the residue micropegmatite were, in other cases, a mixture of silica, alumina, and alkalis, it was in this Transvaal norite entirely free from alkalis, and richer in alumina, giving rise to the crystallization of quartz and, instead of feldspar, the alumina silicate, sillimanite.

An interesting question is also the cause of the relatively coarsely crystalline character of this dyke norite, developed even at its immediate contact with the sedimentary rock. This character may owe its existence to two causes—

(a) This portion of the dyke may have solidified at a great depth, the tuff through which it breaks having been already intensely heated by the preceding eruptive magma. Thus a slow cooling, and consequent large crystallization, would be rendered possible.

(b) The intruding eruptive mass consisted of an aquo-igneous magma with a low melting-point, which was therefore capable of large crystalline development at a far lower temperature than would be the case with an anhydrous basic magma, possessing a high fusion-point.

The first cause (a), alone, is here impossible, for the tuff has been but very slightly metamorphosed through heat; but it is possible that both causes (a and b) may have combined to effect this crystallization.

This occurrence, again, strongly resembles that of the hypersthene-diallage-gabbro dyke in Lydenburg District, near Setigalanga, discovered and described by Cohen.

(vii a) *The metamorphosed rock of the Magaliesberg series*, through which this norite breaks, has every appearance, both macroscopic and microscopic, of a volcanic tuff, or so-called "banded porcelain-jasper." It is a much laminated or banded, very fine-grained, compact rock, of a reddish slate-blue coloration, in its unaltered condition, but becomes black and loses its sedimentary characters at the immediate dyke contact. It possesses an irregular or conchoidal fracture, but has no cleavage, either along the plane of bedding or after any direction. Thin layers of a reddish colour are intercalated with slate-blue bands, and a finely banded appearance is given to the rock by the presence of many thin deposits of secondary calc-spar and iron pyrites, lying parallel to the plane of bedding. The specific gravity is very high, being 2.9 at a distance from the dyke and 3.0 at the immediate contact. This difference of specific gravity may be accounted for by the concentration of iron-ore near the contact. Sections made of the unaltered and also of the contact rock, show a very fine-grained brown groundmass, made up of quartz, small irregular grains of decomposed feldspars, biotite, black iron-ore, iron pyrites, and a good deal of secondary calc-spar, with a porodine amorphous base. The secondary metamorphic minerals

¹ Quart. Journ. Geol. Soc., vol. L (1894), p. 311 seqq.; vol. li (1895), p. 125 seqq.; vol. lii (1896), p. 320 seqq.

at the contact consist of well-crystallized pseudomorphosed individuals, probably originally cordierite, in a dark, impellucid groundmass, the latter gradually becoming more pellucid towards the unaltered rock, and resolving itself into concretions of fibrous sillimanite and biotite, with a good deal of iron-ore, passing over, by degrees, into the unchanged rock. The largest individuals of secondary contact minerals formed in the tuff are but a fraction of a millimetre in length, and are wholly pseudomorphosed by chalcedony or calcite, rendering their identification extremely difficult. However, the behaviour of the chalcedony fibres under polarized light reveals an arrangement similar to the triple twinning of cordierite, the six-sided crystal form being divided into six divisions, or three pairs, each two opposite fields of chalcedony fibres extinguishing simultaneously in their turns, during the rotation of the microscope table. This disposition of the chalcedony, together with the crystal forms, renders it very probable that the original contact-mineral was cordierite.

Small particles of the pyroxenes, evidently from the eruptive norite, occur imbedded in the tuff near the contact, and are usually encircled by calc-spar. It is remarkable that the igneous dyke mass has had so confined a metamorphic effect on this tuff, for the contact zone, in which the secondary minerals lie, has only a breadth of from a few millimetres up to several centimetres (Fig. 12). This may be accounted for either by the limited size of the dyke mass, or a more satisfactory explanation may be given in hydrometamorphic action, by which the large crystalline tendency of the norite itself may also be explained.

Of the various authors who have described the Magaliesberg Beds, Hatch appears to be the only one who attaches an igneous origin or ascribes a tufaceous character to the shales of that formation. In his newly published work on Transvaal geology, he says¹ that the shales are "closely associated with basic volcanic rocks, and probably owe their origin to the decomposition of the latter, partly to the original association of the flows with deposits of volcanic ash." Hatch's testimony is valuable in confirming the author's conclusions that these Magaliesberg shales from the Marico District are tuff.

(viii) *Enstatite-Pyroxenite, from Central Marico District.*

Some miles westward of the preceding norite dyke occurs a large sheet or overflow of pyroxenite which forms, according to Mr. Dörffel, the principal rock of about 100 square miles in that neighbourhood. This mass undoubtedly breaks through, or is intercalated between, the beds of the Magaliesberg formation, but no contact of the igneous and sedimentary rock has, until now, been observed. This rock is solely composed of an aggregate of medium grained, xenomorphic, green

¹ Frederick H. Hatch, "A Geological Survey of the Witwatersrand," etc.: Quart. Journ. Geol. Soc., vol. liv (1898), p. 90.

enstatite granules, equidimensional, and of irregular contour, generally of about 3 mm. in diameter, but occurring up to 6 mm. across. No cementing material whatever is present. The specific gravity, as averaged by several measurements, is 3.297.

Also, under the microscope only one mineral is noticed, namely, the yellowish-green, weakly pleochroic enstatite; no difference in specific gravity was noted during the treatment of the powder in heavy solutions.

Thin sections were difficult to prepare, as the grains spring apart very easily during the grinding, because of the lack of cementing material, and through weak cohesion. The enstatite possesses a perfect cleavage $\parallel \infty P (110)$, but none was observable after the pinacoids. However, a strongly fibrous striation after the pinacoids is often noticeable, and numerous inclusions of light-coloured mineral plates, or of black needles, are imbedded parallel to the pinacoidal planes. (Fig. 25, Plate V.) The included colourless mineral plates remind one strongly of the interlarded felspar lamellæ of the Hex River norite.¹ In this case, the presence of plagioclase lamellæ in the pyroxene may perhaps be accounted for by the poverty of the pyroxenite magma in the felspar-forming constituents and the inclusion of the incipient microscopic lath-shaped crystals of plagioclase in the pyroxene mass, during the contemporaneous crystallization of both minerals. As a matter of fact, this view is supported by the analysis of the pyroxenite *in toto*, which possesses far too high a percentage of lime and alumina for an enstatite, a short calculation showing that almost 4.5 % of $\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$, or anorthite substance, is present in the pyroxene. Thus sections $\parallel \infty \bar{P} \infty (010)$ reveal the broad sides or faces of the included anorthite plates, whilst an enstatite grain cut $\parallel \infty \bar{P} \infty (100)$ exhibits a strong vertical striation, caused by the thin edges of the anorthite leaves lying $\parallel \infty \bar{P} \infty (010)$. The quantity of these inclusions varies greatly in the different grains, the striation sometimes growing fainter and fainter, until at length it is no more observable. This reminds one of the behaviour of the felspar inclusions in microperthite and microcline.

The whole rock was analyzed *in toto*, being pure enstatite, giving the result as seen in analysis I:—

		I.			II.
SiO ₂	...	55.23 %	...	..	53.00 %
TiO ₂	...	0.44 %	...	...	—
Al ₂ O ₃	...	2.08 %	...	...	2.60 %
Fe ₂ O ₃	...	3.94 %	...	...	—
FeO	...	6.25 %	...	...	9.27 %
MgO	...	29.29 %	...	...	25.50 %
CaO	...	1.68 %	...	...	6.60 %
MnO	...	—	...	...	2.00 %
H ₂ O	...	1.12 %	...	..	—
Total	...	100.03 %	...	...	98.97 %
Specific gravity	...	3.297	...	...	—

¹ See ante, p. 25.

I = analysis of this Marico pyroxenite.

II = analysis of Lydenburg pyroxenite by Maskelyne.¹

The numbers of the following table were calculated from analysis I:—

	Mg	Ca	Fe ^{II}	Fe ^{III}	Al	Si	O
% of elements ...	17·574	1·200	4·860	2·758	1·101	25·774	45·203
Atomic quotient	0·732	0·030	0·0868	0·0492	0·0408	0·9205	2·825

from which the subjoined proportions are obtained:—

$$R : Si = 1 : 1$$

$$Mg : Fe^{II} = 1 : 0·12$$

$$Mg : (Fe^{II} + Ca) = 1 : 0·16$$

$$Fe^{II} : Ca = 1 : 0·35$$

$$Fe^{III} : Al = 1 : 1$$

$$Fe^{II} : Fe^{III} = 1 : 0·57$$

$$RO : R_2O_3 = 1 : 0·1$$

The following table of isomorphous compounds of this mineral is given:—

	Mg O	Ca O	Fe O	Fe ₂ O ₃	Al ₂ O ₃	Si O ₂		%
Atomic quotient	0·7322	0·0300	0·0868	0·0246	0·0204	0·9278		
Mg O · Si O ₂ ...	0·7077	—	—	—	—	0·7077	1·4154	77·03
Ca O · Si O ₂ ...	—	0·0096	—	—	—	0·0096	0·0192	1·55
Fe O · Si O ₂ ...	—	—	0·0868	—	—	0·0868	0·1736	9·45
Mg O · Fe ₂ O ₃ · 4 Si O ₂	0·0246	—	—	0·0246	—	0·0984	0·1476	8·03
Ca O · Al ₂ O ₃ · 2 Si O ₂	—	0·0204	—	—	0·0204	0·0408	0·0816	4·44
						0·9433	1·8374	100·50

Deficiency of Si O₂ = 0·0155

This is, therefore, essentially a magnesian silicate, i.e., it possesses the constitution of enstatite. Rather much lime, iron, and alumina are present, the lime and alumina being accounted for by the presence of intergrown anorthite plates.

The only other rock-forming pyroxenite recorded from the Transvaal is that described and analyzed by Maskelyne, whose analysis (No. II) is given for comparison. It shows a much greater percentage of lime, somewhat more alumina, but less magnesia than the Marico rock, the total amount of iron being about equal in both cases. Maskelyne

¹ Maskelyne, "Rock-forming Pyroxenite," etc. : Phil. Mag., vol. vii (1879), p. 135.

accounts for the lime by the presence of numerous diopside grains in the pyroxenite rock, which are entirely absent in this rock.

The Marico pyroxenite may also be regarded as an extreme modification of a norite, in which the rhombic pyroxene is less pleochroic, and contains less iron but more magnesia than the strongly pleochroic rhombic pyroxenes of the norites; whilst the plagioclase is only present in very minute quantity.

III.

SUMMARY.

The rocks of the Zwaartkoppies range belong to the Norite family, and not to the gabbros, under which latter appellation they have been known until now. The principal ferro-magnesian constituent is a strongly pleochroic hypersthene, and the felspar is bytownite or anorthite. Towards the east end of the range transitions from the normal norite of the west end, towards normal gabbro and into diabase, are observed, quartz, biotite, and a salite-like pyroxene sometimes taking part in the constitution.

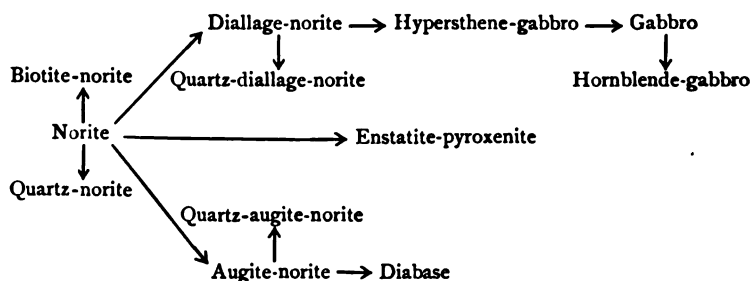
The norites and gabbros of the Marico District are very similar to those of the Zwaartkoppies, whilst the gabbros described by Cohen, Dahms, and Molengraaff from Lydenburg, Potchefstroom and Marico Districts, and from the Rhenosterkop in the Orange Free State, possess strikingly similar characteristics.

The enstatite-pyroxenite of the Marico District also presents features similar to those of the Lydenburg pyroxenite, investigated by Maskelyne.

Amongst the interesting characters encountered during the course of the investigation, the following may be mentioned:—(1) The numerous and beautifully developed mutual intergrowths of hypersthene and diallage || OP (001), in the diallage-norite near the east end of the Zwaartkoppies, causing, at times, apparent strong parting or polysynthetic twinning after that plane; (2) the numerous interlamellated folia of biotite after the pinacoids, in the hypersthene and diallage of the norite near Sephton, Marico; (3) the great number of basic plagioclase plates, and individuals, in the hypersthene of the norite near Rustenburg, as well as in the enstatite of the Marico pyroxenite; (4) the high percentage of iron in all the pyroxenes, and unusually large quantity of lime in the rhombic pyroxenes; (5) the appearance of primary micropegmatite and quartz in the norites; (6) the coarsely crystalline character of the diallage norite dyke in Central Marico, even at the junction with metamorphosed sedimentary rock; (7) the small metamorphic effect of this dyke mass on the sedimentary rock (tuff) at the contact; (8) the absence of olivine in the majority of Transvaal norites and gabbros described up till now.

Further, suggestions have been offered by the author as to the probable genesis and formation of the intimately intergrown hypersthene and diallage, and other interesting phenomena.

The following rocks of the Gabbro family have been described from the Pretoria, Rustenburg, and Marico Districts by Cohen, Dahms, and Molengraaff, as well as in this paper :—



This arrangement does not imply any direct transition of the one rock into the other, but it appears probable that these various rocks have originated from a common magma through differentiation.

IV.

APPENDIX.

OTHER SOUTH AFRICAN ROCKS.

- (i) *Gneiss and Granite Families*: (a) Normal Rocks.
(b) Anorthoclase Rocks.

(a) *The Normal Rocks.*

The Gneisses.—Hübner¹ has already described the geological features of the rocks here examined, which occur in that part of Southern Matabeleland and Northern Bechuanaland lying between Shoshong and the Matoppo Hills. He has also discussed their relations to the granite and crystalline schists of that neighbourhood. According to him these and the crystalline schists form the principal rocks, besides the granite, of this part of South Africa. The gneiss and granite are in some parts so intimately connected with each other, that it is sometimes difficult to say whether the rock belongs to the one or the other family, it being then termed "gneissic-granite." The contorted and much folded condition of the strata shows that the gneiss has been submitted to the action of intense dislocation and pressure, and the granite, which forms isolated hills and kopjes along the road between Shoshong and Tati, often contains numerous large and small fragments of gneiss enclosed in its mass; the number of inclusions being in parts so great as to form a gneiss-breccia. Beyond Tati, at the Mangwe River, gneissic-granite also occurs, carrying included fragments of hornblende schist. The

¹ See loc. cit.

gneiss, possessing white felspar, weathers much more easily than the granite, which contains reddish-coloured felspar.

The *Amphibole-gneiss*¹ from Shashi River, near Tati, is a dark-coloured, medium-grained rock, consisting of quartz, plagioclase, and green hornblende, in about equal quantities. Very numerous small zircon and apatite crystals, some sphene, and colourless epidote are present as accessory constituents. The rock is much crushed, and contains broken felspars, with undulose extinction of the constituents. The plagioclase, with an extinction of about 25°, is much twinned, often doubly after the usual laws, and contains many acicular inclusions of a colourless mineral $\parallel c$. The hornblende is strongly pleochroic, from green to brown, and is often singly twinned $\parallel \infty \text{ } \neq \infty$ (100). Very numerous short, dark, thick rods, with square cross-section, supposed to be rutile, also long pellucid needles and short zircons, are included in the hornblende, lying mostly $\parallel c$, but also in other directions. The quartz contains the usual CO₂ inclusions, and long hairs of rutile. Colourless to faintly yellow epidote is also present in considerable quantity, principally grouped around the fresh hornblende and in aggregates of lath-shaped crystals.

This rock is probably similar to the amphibole-gneiss, free from orthoclase, described by F. H. Hatch² from Antoby, Madagascar.

Microcline-gneiss from the Gokwe River, alternately interbedded with hornblende schist. The ferro-magnesian constituents are meagrely represented by a little biotite, while the felspars predominate over the quartz. The quartz contains the usual CO₂ inclusions, and often forms vermicular micropegmatitic intergrowths in the felspar grains. The felspars are white, and consist chiefly of microcline, but also of a much-twinned plagioclase of very low extinction. The microcline is often interlarded with colourless lamellæ of another felspar, forming a microperthite. Minute zircon crystals are also frequent.

Amphibole-gneiss, forming low-lying hills running parallel to the road between the Gokwe and Serule Rivers. This is a light-coloured, fine-grained rock, principally composed of pale reddish felspars and colourless quartz, with irregularly distributed patches of dark greenish-blue hornblende, along the planes of foliation. The accessory minerals consist of large crystals of apatite, brownish sphene, numerous small zircons, and rutiles. A few leaves of dark biotite and a little iron-ore (ilmenite and specularite) are also present. This rock shows the usual signs of extreme cataclastic action. The felspars consist of orthoclase and plagioclase, the latter predominating. The orthoclase is frequently developed as microcline and microperthite, and is sometimes kaolinized, whilst the plagioclase is a low-extinguishing, much-twinned oligoclase. The felspar often forms micropegmatite with the quartz.

¹ Similar rocks, occurring in German West Africa, have been termed "Diorite-Schist" by H. Wulf, because of the absence of orthoclase. See H. Wulf, "Beitrag zur Petrographie des Hererolandes in Süd-West Afrika": Inaugural Dissertation, Leipzig, 1887, p. 18.

² Quart. Journ. Geol. Soc., vol. xlv (1889), p. 340.

The hornblende is pleochroic, from greenish-blue to brownish-green, and mostly contains large inclusions of intergrown sphene $\parallel c$. It is sometimes almost completely decomposed to yellow epidote. The sphene is mostly associated and intergrown with the hornblende, but also occurs encircling the titanite iron-ore grains.

Biotite-gneissic-granite forms the low hills near the road between Motlantu and Shashi River. It only differs from the amphibole gneisses in that it contains biotite instead of hornblende. These biotite leaves are irregularly distributed in large patches, along parallel planes, giving the rock the characteristic gneissose appearance. The microscopic structure of the rock is that of a gneiss. According to Hübner this rock forms the intermediate stage between the granite and gneiss of this district.

Amphibole-biotite-granite, from the hills surrounding the saltpan, Zoutpansberg District, Transvaal. Two varieties, large- and fine-grained, were examined. The large crystalline rock contains quartz, pale flesh-coloured felspar, hornblende, and biotite as its principal constituents, individuals attaining a length of 20 mm. and more, while the finely crystalline variety carries a much higher proportion of quartz, and the hornblende is entirely replaced by biotite. The accessory minerals present are numerous perfectly-formed zircons arranged in groups, or lying singly in the quartz and felspars, up to 0.12 mm. in length, together with very little apatite and iron-ore. No muscovite was seen.

The felspars consist of a low-extinguishing, much-twinned plagioclase, giving up to 12° extinction on P, and microperthite. The quartz contains numerous liquid inclusions and many short crystals of zircon. It very seldom forms micropegmatite with the felspar. The hornblende is strongly pleochroic, from dark-green to brown, and contains inclusions of biotite, apatite, and zircon. No signs of pressure were noticed.

Microcline-granite, from the Yokeskey River, about 8 miles north of Johannesburg, and from the Half Way House between Pretoria and Johannesburg. The author's observations on this rock agree with those made by Molengraaff in his excellent description of it,¹ from specimens taken from other parts of the large granite massif. It has also been described by Schenck, Penning, and Gibson. It may here be remarked that in the comparatively fresh Yokeskey River specimen, a regular mutual intergrowth between biotite, muscovite, and green pleochroic chlorite was observed parallel to the cleavage traces, and it would appear that, as Molengraaff suggests, the chlorite has been derived from the primary biotite. A good deal of the muscovite is primary, containing tiny zircon inclusions, but much is secondarily derived from the felspar through decomposition. Broken needles of rutile in the quartz grains and contorted mica folia, as well as the bent and broken felspars, combined with undulose extinction of the quartz and felspars, indicate considerable cataclastic action. This probably explains, as Molengraaff observes, the cross-hatching structure of the microcline.

¹ Loc. cit., p. 184.

Felspar-porphry, as a dyke in granite, Inyati, Matabeleland. This is a greyish rock, and consists of numerous white felspar (plagioclase) crystals, up to 0.6 cm. long, lying in a microcrystalline, dark-coloured groundmass. Under the microscope it is seen that, besides the plagioclase, automorphic green hornblende and brown augite crystals occur as porphyritic constituents, and that the groundmass is composed principally of round quartz grains, together with felspar, hornblende, and augite. A small quantity of iron-ore is present, as beautiful skeleton crystals of ilmenite, also a little apatite. The plagioclase is somewhat decomposed, and has a low extinction of 10° – 12° . A great deal of the green hornblende is secondarily derived from the augite, but a large quantity is automorphic and primary. Its pleochroism ranges from yellowish-green to light brown. It is often singly twinned $\parallel \infty P \infty (100)$. Sometimes it forms parallel intergrowths with the augite $\parallel c$. The augite is mostly uralitized, but fresh cores are often found in the uralite mass.

(b) *Anorthoclase Rocks.*

An interesting group of rocks are the granites, the syenite, and the porphyry now to be described, which contain as their chief felspathic constituent a white or reddish-coloured, triclinic, soda-potash felspar, resembling the so-called anorthoclase.¹ This mineral has up till now been principally found in rocks from Africa and its islands — Kilmanjaro,² Pantellaria,³ Teneriffe,⁴ as well as in the Azores⁵ and Sweden.⁶ In all of these cases the mother rocks were young eruptives, e.g., basanite (Kilmanjaro), trachyte (Kilmanjaro and Azores), andesite, pantellerite (Pantellaria), and glassy lavas (Teneriffe), except in Sweden, where they are augite-syenite and so-called "Rhomben-porphyr." Here the rocks are either Plutonic or Pre-Tertiary, so that there appears to exist a complete rock family, from the holocrystalline Plutonic to the glassy volcanic members, whose chief constituent is a triclinic soda-potash anorthoclasic felspar.

It seems also probable that a series of potash-soda felspars exists with orthoclase and albite as the two extremes, composed of isomorphic mixtures, in varying proportions, of Or and Ab, with intermediate soda-orthoclases and potash-albites, forming also transitions into the

¹ This name was introduced by Rosenbusch (see "Mikroskopische Physiographie," 1892, p. 679), but Zirkel has suggested the term "Parorthoclase" as more appropriate to this mineral (see F. Zirkel, "Lehrbuch der Petrographie," Band i, 1893, p. 238).

² H. A. Miers, "Orthoclase from Kilmanjaro," etc.: Min. Mag., vol. vii (1886), No. 32, pp. 10–12. L. Fletcher & H. A. Miers, "Supplementary Note on Felspar from Kilmanjaro": ibid., 1887, No. 34, pp. 131–2. See also Zeitschr. f. Krystallographie, vol. xiii (1888), p. 385. Mügge, Neues Jahrb. für Mineralogie, etc., Beil. Band iv (1886), p. 591. J. S. Hyland, Geol. Mag., dec. iii, vol. vi (1889), p. 160; and "Die Gesteine des Kilimandscharo und dessen Umgegend": Mineralog. und Petrograph. Mittheil., vol. x (1889), p. 250.

³ E. Förster, Groth's Zeitschrift für Krystallographie, vol. i, p. 547; also vol. viii, pp. 125–201.

⁴ Deville, Comptes Rendus, vol. xix (1844), p. 46.

⁵ Mügge, Neues Jahrb. für Mineralogie, etc., vol. ii (1883), p. 192. Fouqué, Bull. soc. minér., 1884, p. 197.

⁶ Mügge, Neues Jahrb. für Mineralogie, etc., vol. ii (1881), p. 106. Brögger, Zeitschrift für Krystallographie, vol. xvi (1890), p. 43.

albite-anorthite plagioclase series of the triclinic feldspars. This would favour the modern view that orthoclase itself is a triclinic mineral.

Rocks with these intermediate feldspars as principal constituents would therefore occupy the gap between the granite and syenite families on the one hand, and the diorite and diabase families on the other. If a distinctive name were given to such rocks, it would be of much use to the petrologist in classifying them, for it is difficult to decide whether such a rock should be termed "syenite" or "diorite," "porphyry" or "porphyrite," and so on. Förster's name "pantellerite" applies only to the volcanic equivalents of these rocks.

The author would like to suggest the following names, "**hatherlite**" for the syenitic holocrystalline facies, and "**pilandite**" for its porphyritic equivalent, after the localities where two such rocks herein described are found.

In the case of the South African rocks of this class, the petrologist cannot assert from purely optical characters, without chemical investigation, that any polysynthetically twinned feldspar is a true plagioclase belonging to the albite-anorthite series, and not anorthoclase; nor can the percentages of Ab and An be calculated, or the position of the feldspar in the lime-soda series be determined from the value of the extinction angle, as may usually be done.

Amphibole-pyroxene-syenite ("**hatherlite**"), forming the principal mass of the hills near the powder factory ("Eerste Fabriek") situated on the farm Hatherley, 15 miles E.N.E. of Pretoria.

This is a reddish medium to large-grained rock, composed principally of anorthoclasic feldspar with sparingly distributed brown hornblende, a pale-green pyroxene and biotite. Very little quartz is present, which phenomenon warrants the name of syenite. It may be a local quartzless modification of the amphibole-biotite-granite of the Springbok Flats, north of Pretoria, containing reddish feldspars, described by Cohen.¹

As accessory constituents occur numerous large crystals of apatite, up to 3 mm. in length, muscovite, titanite, ilmenite, and large zircons up to 0.55 mm. long.

The large brown individuals of hornblende, attaining a length of 10 mm., are almost entirely decomposed to epidote, chlorite, calcite, and iron hydroxides. The pale-green to colourless salite-like pyroxene is present in smaller quantity than the hornblende, and has an extinction of up to 45°, being also very decomposed.

The feature of this rock is the feldspar. The individuals attain a length of 15 mm., and are composed of an inner core (I) (see Fig. 26) of white feldspar surrounded by a girdle (II) of flesh-coloured to brownish-red material, with a gradual transition of the white into the red. Under



FIG. 26.

¹ E. Cohen, "Über eine nördlich von Pretoria (Transvaal) in Granit gelegene Salzpfanne": Separat Abdruck aus Tschermak's Min. u. Petrogr. Mitth., p. 3.

the microscope both the white and the red modifications of the felspar are seen to be polysynthetically twinned, with low extinction of 9° – 12° on P; but the red is more decomposed than the white, being almost impellucid. In order to ascertain if any chemical or physical differences exist between the white and red felspar material, they were separated by means of Klein's heavy solution, the white core being the heavier, having a specific gravity of 2.65, while that of the reddish girdle is about 2.56. Chemical investigation (see analyses) revealed the fact that both modifications are soda-potash felspars, or anorthoclases, the inner white core containing more lime and alumina, but less silica, than the reddish girdle, the reddish coloration evidently being due to iron hydroxides.

The following analyses (I and II) were made of the white and red felspars:—

				I.		II.		III.
Si O ₂	...	...	...	61.81	...	64.06	...	62.17
Al ₂ O ₃	...	..	...	24.68	...	21.68	...	23.52
Ca O	...	...	...	2.71	...	1.87	...	2.90
Na ₂ O	...	...	...	7.53	...	7.53	...	6.80
K ₂ O	...	..	...	3.37	...	4.50	...	4.97
Total	...	...	...	100.10	...	99.64	...	100.36
Specific gravity	...			2.65	...	2.56	...	—

I = analysis of white anorthoclase from this rock; contains also 0.99% Fe O and 0.11% Mg O.

II = analysis of red anorthoclase from this rock; contains also 1.2% Fe O and 0.34% Mg O.

III = analysis of anorthoclase from Kilmanjaro, by Fletcher and Miers, after elimination of Fe₂ O₃, Mg O, and H₂ O. This analysis is given for comparison.

The component compounds of these anorthoclases, namely, Orthoclase (Or) = K₂ Al₂ Si₆ O₁₆, Albite (Ab) = Na₂ Al₂ Si₆ O₁₆, and Anorthite (An) = Ca Al₂ Si₆ O₁₆, are present in the following percentage and proportions, both the extremes An and Or being used as a unit in the calculation for the sake of comparison:—

	I.			II.			III.		
	%	Proportions.		%	Proportions.		%	Proportions.	
Ab ...	66.94	5	3.4	65.60	7.7	2.5	58.22	4.2	2
Or ...	19.73	1.5	1	25.87	3	1	28.02	2.04	1
An ...	13.33	1	0.7	8.53	1	0.33	13.74	1	0.5

In this case the extinctive angle on P is very large compared with other anorthoclases up till now investigated: for instance, in those

from Kilmanjaro, Fletcher found a value of $4^{\circ} 20'$, and Hyland obtained $1^{\circ}-2^{\circ}$ as the angle (Kibo Peak), while the anorthoclase of Teneriffe gave an extinction of 4° on P. The specific gravities also agree with those found by Hyland and Mügge for the Kilmanjaro anorthoclases, and with that of the anorthoclase from the island of Terceira in the Azores. However, no microclitic cross-hatching is to be seen here, as observed by Fletcher and Hyland in the Kilmanjaro mineral.

Although the angle of extinction is higher than that observed up till now in any anorthoclase, the nature of the mineral as true anorthoclase is proved by the chemical composition.

A porphyritic facies of the anorthoclase rock is the *Pilandsberg porphyry (pilandite)*, forming the greater part of the Pilandsberge, north of Rustenburg, Transvaal. It is a somewhat vesicular, dark-red, fine-crystalline rock, possessing large dark-red crystals of felspar porphyritically developed, up to 20 mm. long, in its finer-grained groundmass, and intersprinkled with a little dark amphibole. The red coloration of the rock is due to the red feldspars, which are mostly small lath-shaped crystals, often occurring in radially arranged aggregates. Quartz is almost quite absent, only a few grains being seen, and thus this rock may be regarded as a porphyritic facies of the foregoing type of syenite or "hatherlite." As accessory minerals occur a large number of sphene crystals, some apatite, and iron-ore. The hornblende is decomposed to chlorite, epidote, etc., and the vesicles of the rock are principally filled in by calc-spar and blue fluor-spar.

The anorthoclastic felspar is rather clouded, and is usually polysynthetically twinned on each side of a central Carlsbad twinning plane. It is also often twinned after the Bavenoer law. The extinction on P is about $10^{\circ}-12^{\circ}$. This mineral gave a microchemical reaction for potash, and coloured the flame violet; accordingly it was separated and a chemical analysis was made, giving the following results:—

Si O ₂	...	...	...	...	66.31 %
Al ₂ O ₃	...	...	...	...	20.60 %
Ca O	...	...	...	...	0.48 %
Na ₂ O	...	...	...	...	7.54 %
K ₂ O	...	...	...	...	4.92 %
Total	...	...	...	...	99.85 %
Specific gravity	...	...	...	...	2.60

from which the following percentages and proportions of Ab, Or, and An were calculated:—

				%		Proportions.	
Ab	..	...	68.20	28.5	2.32		
Or	...	...	29.39	10.2	1		
An	...	...	2.41	1	0.08		

The Fe_2O_3 (2.88 %), Mg O (0.14 %), and H_2O were eliminated from this analysis. The red coloration of the feldspars, as before, is probably caused by the presence of hydrous iron oxides. This anorthoclase is therefore almost exclusively a mixture of orthoclase and albite, in the proportions of 1 to 2.3.

This rock breaks through the granite and Magaliesberg Beds, and contains many enclosures of fragments of granite and shales, which are, however, according to Hübner, very little altered by the eruptive rock.

The anorthoclases of these two rocks both carry a certain percentage of lime, almost 3 % in the preceding rock, and it does not therefore appear impossible that there exist feldspars with every gradation between Or and Ab on the one hand and Or + Ab + An and Or + An on the other hand.

Hornblende-granite from 30 miles north of Middelburg. The red feldspar gives this rock a reddish appearance. It is a medium-grained rock, consisting principally of red feldspar, quartz, and green hornblende, in even-sized grains, no mineral attaining a greater length than 5 mm. Biotite, iron-ore, apatite needles, and epidote are also present in smaller quantities, and micropegmatitic intergrowth of the quartz and feldspar is frequently observable.

The red feldspar is mostly decomposed to a kaoline-like, impellucid mass, with a little epidote, but where fresh reveals polysynthetic twinning and an extinction of up to 16° . No microclinal cross-hatching could be seen. A microchemical test gave a strong potash reaction, and the violet coloration of the flame was also obtained. These reactions, together with the optical and physical appearance of the feldspar, render it very probable that this is an anorthoclase, similar to the two previous ones.

The hornblende is strongly pleochroic from deep blue-green to brownish-green, and is often arranged in aggregates. The quartz possesses numerous tiny CO_2 inclusions.

Granophyre (graphic granite), alternately intercalated with hornblende schist, Serule, Khama's Land. This was called by Hübner "granite-granulite." It is composed of red feldspar and quartz. The latter occurs as long parallel lenticular intergrowths with the feldspar, like graphic granite, and imparts a somewhat banded appearance to the whole rock. The pegmatitic structure sometimes also attains microscopic dimensions. Besides feldspar and quartz, skeletons of ilmenite surrounded by girdles of leucoxene, a few needles of zircon, and apatites, and some muscovite are present. Much secondary epidote as veinules and grains is found throughout the rock.

The appearance of this feldspar is the same as that of the anorthoclases already described, and therefore this rock is included in the anorthoclase rock group.

(ii) *Crystalline Schists.*

The samples examined are taken from the crystalline schists which are interbedded with gneiss in Northern Bechuanaland and Southern

Matabeleland. At the Shashi River occurs a *muscovite-schist*, forming clearly bedded layers between the gneiss beds. It is a light-yellowish, fine-grained, foliated rock, and possesses the appearance of a sericite schist. The layers are much contorted and folded, even in the hand-specimen, like the gneiss of this district. The principal constituents are quartz, muscovite, and staurolite, together with a little zircon and fibrolite. The quartz, which is about equal in quantity with the muscovite, is present as small grains, and forms here and there lenticular aggregates of larger granules. It contains few CO_2 inclusions arranged in bands, but numerous bent or broken rutile hairs.

The muscovite leaves show the cataclastic action on the rock very markedly as they lie in rows along sinuous curves, and are bent and disturbed particularly where the curves are sharp.

A good deal of yellowish-brown staurolite is present, mostly as rounded grains, but also in well-formed crystals, and innumerable small crystals of zircon are scattered throughout the rock in the muscovite and quartz.

At the Gokwe River, a fresh dark-green, medium-grained *hornblende-schist* is found, forming numerous intercalations with the gneiss. It consists almost exclusively of a green xenomorphic hornblende, but contains a considerable quantity of a colourless hornblende (tremolite or grammatite) and a very little primary quartz. The green hornblende is pleochroic, from green to greenish-yellow, and possesses the usual characters, but shows an apparent polysynthetic twinning $\parallel \text{OP } (001)$ and $\perp \infty (101)$, with a strong striation of colourless lines parallel to $\infty \perp \infty (100)$ and $\text{OP } (001)$ on the $\infty \perp \infty (010)$ section. The colourless hornblende is present both as independent grains and as parallel intergrowths with the green hornblende $\parallel \text{OP } (001)$ and $\infty \perp \infty (100)$. The striation and apparent twinning in the green hornblende are very probably caused by microscopically developed parallel intergrowths of colourless hornblende. Inclusions of reddish-brown rutile and of zircons are very common. The rutiles are usually in beautifully formed crystals up to 0.2 mm. in length, but also occur as fine hair-like yellow needles lying $\parallel c$ in the hornblende. The small zircons are usually surrounded by a brown pleochroic zone. Black grains of iron-ore often accompany the rutile. The quartz is very scarce, and forms at times a distinctly pegmatitic intergrowth with the green hornblende. Hornblende schist is also found at the Mangwe River, Matabeleland, as included fragments in gneissic-granite.

(iii) *Diorite Family.*

A *quartz-diorite* occurring at the Gokwe River represents a typical, fresh, medium-grained, diorite rock. It possesses a directionless granitoid structure, and consists chiefly of white plagioclase up to 6 mm. long, with dark hornblende and some primary quartz. The hornblende and plagioclase crystallized contemporaneously, the hornblende sometimes possessing automorphic contours, while the quartz

crystallized last in the intercrystal spaces. The plagioclase has a low extinction, up to 9° on P. The hornblende is strongly pleochroic, from dark green to yellowish-brown. A few leaves of biotite are present, and some grains of black iron-ore, principally lying in the hornblende.

Quartz-diorite occurring as a dyke in amygdaloidal diabase on the right bank of the Vaal River below Klipsdrift (Barkly West). This medium- to fine-grained rock consists of dark hornblende and automorphic plagioclase in about equal quantities, and has a somewhat ophitic structure. Under the microscope the plagioclase is seen to be low-extinguishing, and mostly decomposed to a saussurite-like mass. The brown hornblende is often somewhat decomposed, and assumes a greenish colour with a chloritic character. Large apatite individuals are associated with the hornblende. The primary quartz occupies the intercrystal spaces between the other constituents. Beautifully formed large skeleton crystals of ilmenite are plentiful, lying chiefly with and imbedded in the hornblende.

Felsitic pitchstone of the diorite family, intercalated between the beds of the coal formation, about 30 miles north of Middelburg, Transvaal. This is a dark-coloured, compact rock, containing a few crystals of a reddish felspar scattered in the dark base. Under the microscope, plagioclase hornblende and a few olivine crystals are seen, as automorphic forms in the feebly translucent, devitrified base, which shows marked fluidal and perlitic structures. The plagioclase, up to 2 mm. long, possesses few twinning lamellæ, and a low extinction of about 15° . Its coloration reminds one of the anorthoclase in the rocks previously described. The hornblende is somewhat decomposed, but shows a pleochroism from green to brown, and sometimes exhibits evidences of resorption. The olivine is, as a rule, quite decomposed. Quartz grains frequently form the nucleus of the variolitic concretions, and probably represent foreign enclosures, caught up in the molten mass during its eruption or intrusion. In all probability this rock is a devitrified pitchstone, and possessed a glassy base when fresh.

(iv) *Diabase*¹ *Family*.

The diabases of South Africa may be divided, as usual, into two classes :—

(a) Normal Diabases, without olivine.

(b) Olivine Diabases.

(a) *Normal Diabases, without olivine*.

Several specimens of *light-coloured, medium-grained diabases* from the cobalt district about 30 miles north of Middleburg, Transvaal, were examined by the author. They possess the usual ophitic structure, and consist principally of high-extinguishing plagioclase, with a pale-green to colourless *salite-like pyroxene*, uralitic hornblende, and quartz. The

¹ The term "diabase" is here used according to its Continental significance, as defined in Zirkel's "Lehrbuch der Petrographie," vol. ii (1894), p. 621.

latter minerals occupy the irregularly bounded interstitial spaces between the feldspars. Biotite and titanite iron-ore are frequent, and needles of apatite are present in all of the constituents. The plagioclase is anorthite, giving extinction values up to 40° , and is much clouded through decomposition. It forms the greatest bulk of the rock. The pale green pyroxene is xenomorphic, and possesses some characters of diopside, e.g., strong pinacoidal and prismatic cleavage with a marked parting $\parallel OP$ (001). Consequently a strongly-marked "herring-bone" structure is caused by single twinning $\parallel \infty P \infty (100)$. It is often decomposed to uraltic hornblende, chlorite, and biotite. The decomposition attacks it chiefly along the basal parting planes, giving the appearance of regular parallel intergrowth with the uraltite. It possesses a high extinction, up to 45° . As is to be expected with such a light-coloured pyroxene, no excretion of iron-ore takes place upon decomposition. The quartz appears to be primary, and to have crystallized last, but is at times absent. It contains CO_2 inclusions and numerous apatite needles. The primary iron-ore is present in considerable quantity as large grains, generally surrounded by large-sized biotite leaves.

This diabase forms one of the principal intrusive dyke rocks of the Middelburg cobalt district, and sometimes occurs as the bearer of the cobalt lodes. A specimen of the diabase strongly impregnated with cobalt-ore, probably cobaltite or smaltite, was examined microscopically, from which it appears that the ore is of secondary origin. The large grains of cobalt-ore usually occupy the spaces between the feldspars together with the quartz, and are surrounded by a zone of secondary chlorite, calc-spar, and colourless mica, the feldspar in the immediate vicinity often being partially decomposed and impregnated with the ore.

A specimen of a dark-coloured, finer-grained diabase from this district contains the usual diabase augite and ophitic structure. Although very fresh, this rock possesses a great deal of beautiful micropegmatite. The augite and plagioclase are present in about equal quantities.

Diabase intercalated in the Magaliesberg Beds, forming the bed rock of the first valley north of Pretoria. This is a medium-grained, grey-coloured rock, and is much decomposed. It possesses an ophitic structure, and consists of high-extinguishing plagioclase, apparently of two generations, uraltized augite, a little iron-ore, and a large amount of granophyre. The primary plagioclase is much clouded and decomposed, while that of the younger generation is fresh and water-clear, forming with quartz beautifully intergrown micropegmatite throughout the whole rock. The brown augite is almost totally decomposed to brownish uraltic hornblende, green chlorite, and biotite, only one or two fresh cores remaining to identify the original mineral. At times the uraltic hornblende, which is pleochroic from brown to green, could almost be mistaken for a primary constituent. Biotite and chlorite are often mutually intergrown, parallel to the cleavage traces, the biotite being generally accompanied by grains of titanite iron-ore. Quartz is abundant

as single large and small granules, but is developed especially as micropegmatite with the felspar.

Examination of the oft-described *amygdaloidal diabase* from the Vaal River, near Hebron, and from Bloemhof, Klerksdorp, and Pretoria, revealed no features of interest not already described by Dahms¹ and Molengraaff² in their petrographical treatises on the rock. The yellow *epidote rock* of Bloemhof evidently represents the last stage of the decomposition of the diabase, the epidote having entirely replaced the ordinary constituents, crystal for crystal, so that the original contours and structure are preserved. Every stage of this transition may be observed in these rocks.

(b) *Olivine Diabases.*

The author's investigations on specimens of these rocks from various parts of Natal, the Orange Free State, Transvaal, and Matabeleland agree in general with Cohen's excellent detailed descriptions³ of the diabases of the Karoo formation in the Cape Colony and Natal. The sheet diabases all possessed a typical ophitic structure, while the dyke rocks tend to be porphyritically developed. The augites are very often twinned singly $\parallel \infty P \infty (100)$, and the extinction of the plagioclase on P varies from 30° to 35°, proving it to be anorthite. The anorthite possesses but few twinning lamellæ, the lath-shaped individuals usually consisting only of a single pair.

An interesting rock is an *Olivine-diabase-porphyrite*⁴ from the Shashi River, near Tati, breaking through the gneiss as a dyke. It possesses large porphyritically developed plagioclases up to 22 mm. in length, in a medium-grained to a finely crystalline, dark-greenish groundmass. The groundmass is composed of plagioclase, augite, and olivine, with a large amount of iron-ore and apatite as accessory minerals, and numerous patches of a brown vitreous base. These patches contain a great number of microscopic incipient crystals of plagioclase and of a colourless to pale-green pyroxene, lying in a brown, devitrified, glassy base, the latter containing numerous trichites and globulites. The plagioclase is, as usual, high extinguishing, up to 35°, and possesses a well-developed zonary structure. The large augites possess a brownish-violet coloration, and are often twinned $\parallel \infty P \infty (100)$. The iron-ore is mostly ilmenite, and occurs in large grains and grain aggregates lying chiefly with the augite. Small apatite needles are very numerous in the base and also in the felspars. The specific gravity of the rock is 2.9.

(v) *Augitite,*

from the hills which surround the Saltpan, Zoutpansberg, Transvaal. On its weathered surface this rock is covered by a thin coating of

¹ Loc. cit., p. 113.

² Loc. cit., p. 212.

³ E. Cohen, "Geognost.-petrogr. Skizzen aus Süd Afrika": Neues Jahrb. für Mineralogie, etc., Beil. Band v (1887), p. 223 seqq.

⁴ Cohen uses this term for the porphyrites of the olivine-diabases.

rust-brown iron hydroxides, but the freshly fractured surfaces reveal a dark, compact, fine-grained rock. On macroscopic examination it apparently consists entirely of small dark pyroxene individuals, attaining a length of 1 to 2 mm. Under the microscope it is seen to be composed almost solely of a confused mass of long lath-shaped to small acicular individuals of brown to violet-coloured augite, together with a great deal of iron-ore and small shreds of biotite, the latter usually associated with and surrounding the iron-ore. Between the augites appear small patches of a brownish-green material, representing, in all probability, a devitrified glassy base. The specimen examined is much weathered, and although the augite is quite fresh, a great deal of the base is decomposed, forming secondary calc-spar, chlorite, and so on. The augite is often twinned singly $\parallel \infty P \infty (100)$. No plagioclase or olivine could be found. The specific gravity of the augite is 3.1.

(vi) *Some Witwatersrand Dykes.*

The rocks examined are close-grained and dark-coloured, mostly schistose in appearance, and weather to a reddish mass towards the surface. They are often so altered by pressure and decomposition, where they are exposed in the mines or at the surface, that it is frequently very difficult to identify their original characters. Hatch¹ remarks that the Witwatersrand dyke rocks are all practically the same, and belong to the epidiorite family, but two of the specimens here examined do not agree with that description.

Diorite dyke, intersecting the Witwatersrand Beds in the Angelo Mine, East Rand. It is a dark-green, close-grained rock, consisting of long lath-shaped crystals of hornblende, and clouded, low-extinguishing xenomorphic plagioclase, together with numerous grains and aggregates of secondary quartz and epidote, titanite iron-ore, leucoxene, iron pyrites, and chlorite. The hornblende is pleochroic, from brown to green, and nearly every individual is singly twinned $\parallel \infty P \infty (100)$. The decomposed felspar gives rise to a saussurite-like decomposition product.

Norite dyke intersecting the Main Reef in the Angelo Mine, East Rand. This fine-grained, greenish-coloured, schistose rock is very decomposed, showing only here and there traces of the original pyroxenic constituent, which gives straight extinction, and is very probably enstatite. The usual decomposition products of felspar and pyroxene are present.

A dyke from Hartebeesthoek, near Krugersdorp, West Rand, is interesting because of the enormous amount of secondary zoisite developed, resulting from the decomposition of the felspar. It could almost be termed a zoisite rock. Besides the zoisite it contains a mass of small interlacing pale-green needles of hornblende.

¹ Loc. cit., p. 85.

(vii) *Notes on some Auriferous Conglomerate from the Angelo Mine,
East Rand.*

The conglomerate of the Main Reef contains numerous dark-coloured pebbles besides the usual colourless or bluish quartz. Under the microscope these dark pebbles are seen to be fine grained quartzite, impregnated with secondary dust-like pyrites, generally along fissures in the pebbles caused by cataclastic action. The gold, as usual, cannot be observed in a free state, but takes part in the composition of the pyrites. Grains of a pink-coloured corundum, needles of tourmaline and zircon, biotite leaves, and colourless to pale-green amphibole lie amongst the pyrites, muscovite, and chloritic substance between the pebbles.

In the South Reef no dark impregnated quartzite pebbles were seen, but a good deal of green hornblende twinned $\parallel \infty \text{ } \overline{P} \infty (100)$, and many grains of pink corundum, with well-formed crystals of zircon, are present.

The majority of the rocks examined were obtained from the late Bergrath Professor Dr. A. W. Stelzner's geological collection in the Royal Saxon School of Mines, Freiberg, and were collected by Herr A. Hübner in his journey of exploration through South Africa with the explorer Mohr, between the years 1868 and 1870, and by Herr A. Goerz in 1892. The author is much indebted to Professor Dr. R. Beck, Stelzner's successor in Freiberg, both for the suggestion of this theme and for the loan of the rock specimens; also to Mr. D. Dörffel for specimens and geological notes, and to Professor Hall, of Minnesota University, for kind assistance.

The majority of the analyses were executed by Dr. Röhrig, of Leipzig.

The author's most grateful thanks are due to his Professor, Geheimrath Dr. Ferdinand Zirkel, for his unvarying kindness, patient instruction, and valuable advice, and in whose mineralogical institute in the University of Leipzig the foregoing investigations were executed.

EXPLANATION OF THE PLATES.

PLATE I.

- FIG. 1.—Glass inclusions in felspar, with included crystals of ilmenite. *f*, felspar; *g*, glass; *i*, ilmenite. (See p. 12.)
- FIGS. 2 and 3. Isolated diallage granules, lying on face $\infty P \infty$ (2) and $\infty P \infty$ (3), and showing lamellæ of hypersthene $\parallel OP$ (001). (See p. 13.)
- FIG. 4.—Schematic sketch showing mutual intergrowth of diallage and hypersthene in relative proportions. *d*, diallage; *h*, hypersthene. (See pp. 14 and 18.)
- FIG. 5.—Double twinning of plagioclase after the Carlsbad and Manebach laws. (See p. 24.)
- FIG. 6.—Isolated automorphic crystals of hypersthene, from the Hex River norite. $a = \infty P \infty$ (100); $b = \infty P \infty$ (010); $m = \infty P$ (110). (See p. 25.)

PLATE II.

- FIG. 7.—Plagioclase doubly twinned after albite and Bavenoer laws. (See p. 28.)
- FIG. 8.—Ideal section of diallage with needle beds. (See p. 28.)
- FIGS. 9, 10, and 11.—Mutual intergrowth of diallage (*d*) and non-pleochroic hypersthene (*h*). (See p. 30.)
- FIG. 12.—Contact of large crystalline dyke gabbro (*g*) with Magaliesberg tuff (*t*), showing small contact zone (*c*) containing secondary minerals of metamorphic origin. (See p. 35.)

PLATE III.

- FIG. 13.—Diallage showing "herring-bone" structure caused by twinning $\parallel \infty P \infty$ (100), and interlamellated hypersthene $OP \parallel$ (001). Also apparent slight polysynthetic twinning $\parallel \infty P \infty$ (001). (See p. 17.)
- FIG. 14.—Diallage showing "herring-bone" structure caused apparently by polysynthetic twinning bands, and twinning $\parallel \infty P \infty$ (100). (See p. 17.)
- FIG. 15.—Mutual intergrowth of pleochroic hypersthene and diallage, crossed nicols. (See pp. 14 and 18.) Compare Fig. 17, ordinary light.
- FIG. 16.—Intrusion of diallage lamellæ into hypersthene $\parallel OP$ (001), crossed nicols. (See pp. 14 and 18.) Compare Fig. 18, ordinary light.

PLATE IV.

- FIG. 17.—Same as Fig. 15, ordinary light.
- FIG. 18.—Same as Fig. 16, ordinary light. Note diallage impregnated with dark needles.
- FIG. 19.—Showing nucleus of hypersthene encircled by girdle of diallage. (See p. 22.)
- FIG. 20.—Showing the relations of hypersthene (*h*), diallage (*d*), hornblende (*h*), salite-like pyroxene (*s*), and felspar (*f*), to one another in Zwaartkoppies norite. (See p. 24.)

PLATE V.

- FIG. 21.—Ophitic structure, and needle beds in diallage, of Marico gabbro. (See pp. 27 and 28.)
- FIG. 22.—Ditto, crossed nicols, revealing apparent polysynthetic twinning coincident with the needle beds.
- FIGS. 23 and 24.—Microcrystalline norite from Marico. *f*₁, micropertthite-like felspar; *f*₂, plagioclase; *q*, quartz; *p*, pyroxene; *b*, biotite. (See p. 33.)
- FIG. 25.—Microscopically interlamellated tabulæ of plagioclase in enstatite of Marico pyroxenite. (See pp. 25 and 39.)

PLATE I.

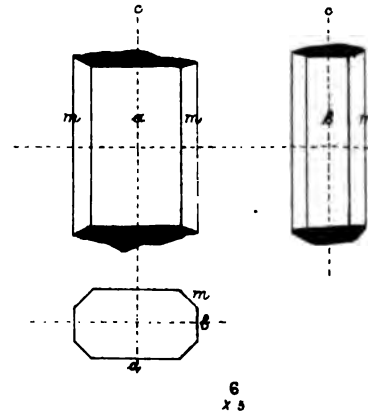
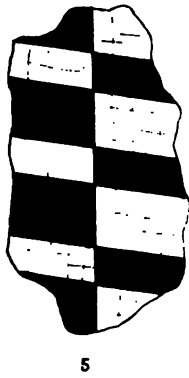
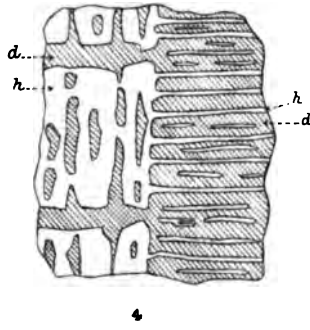
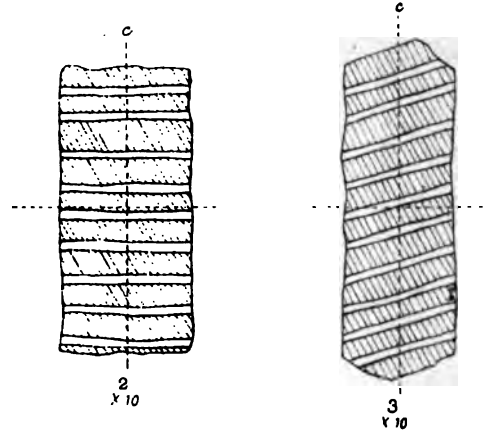
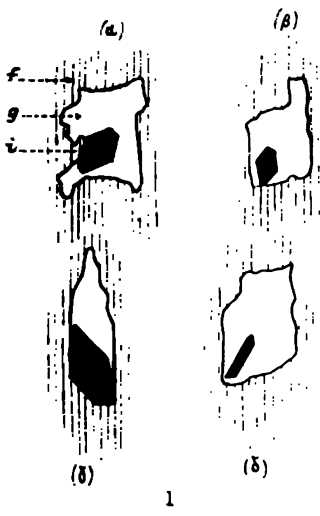
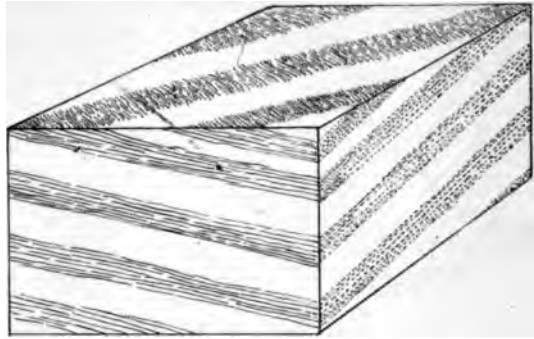


PLATE II.



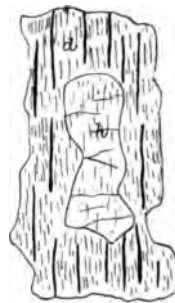
7



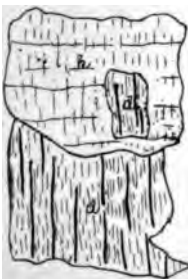
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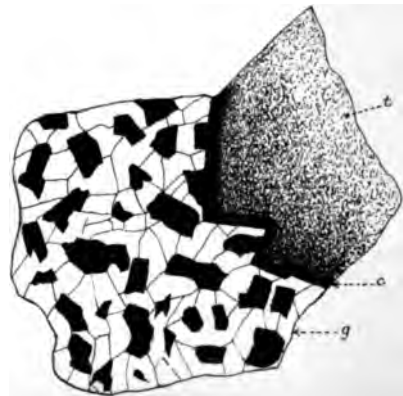
9



10



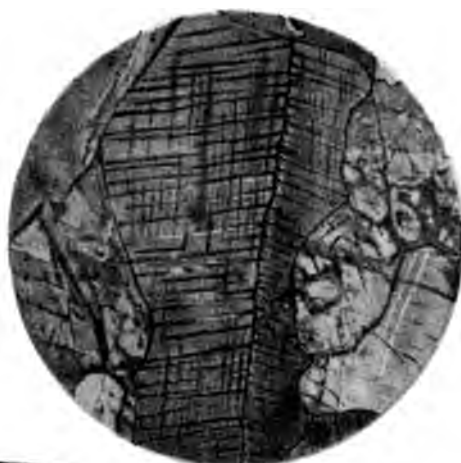
11



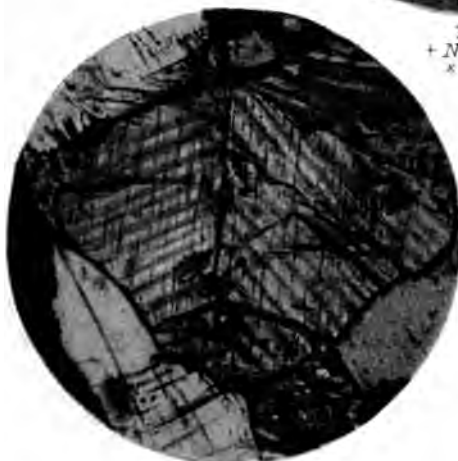
12
nat. size



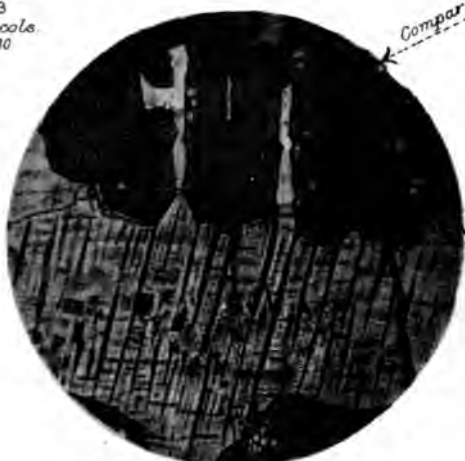
PLATE III.



13
+ Nicols.
x 30



14
+ Nicols.
x 30



15
+ Nicols.
x 45

Compare



16
+ Nicols.
x 35

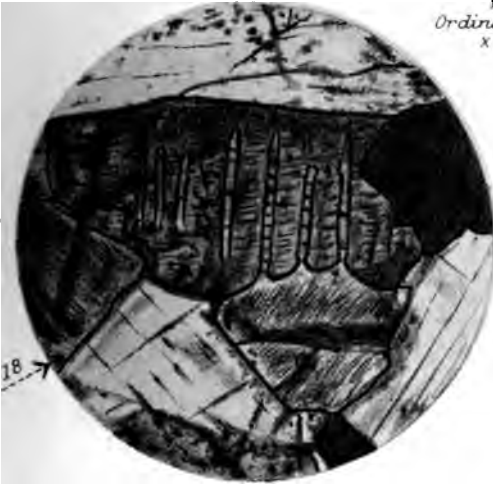
Compare figs 16

PLATE IV.

figs 15 & 17.



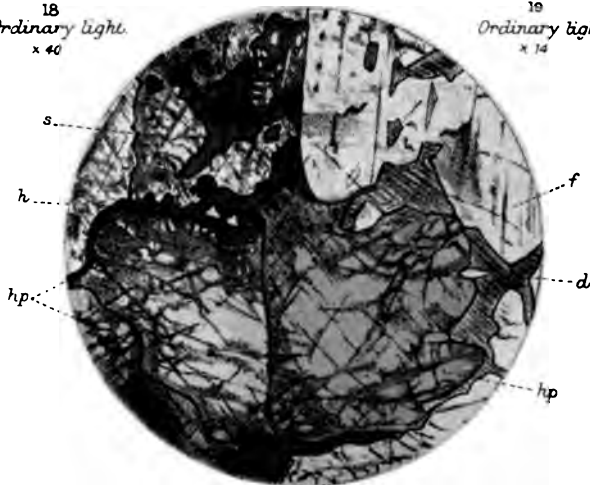
17
Ordinary light.
x 50



18
Ordinary light.
x 40



19
Ordinary light.
x 14



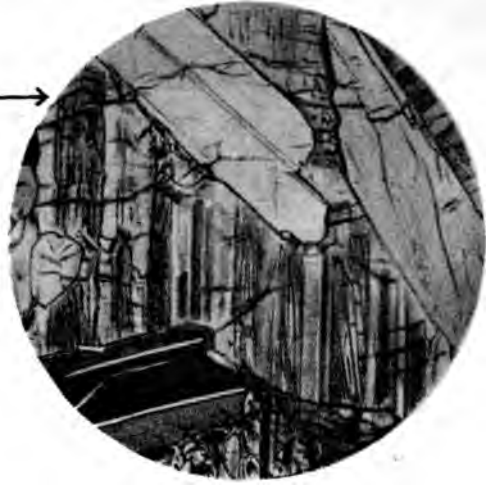
20
Ordinary light
x 20

West. Norman chromo

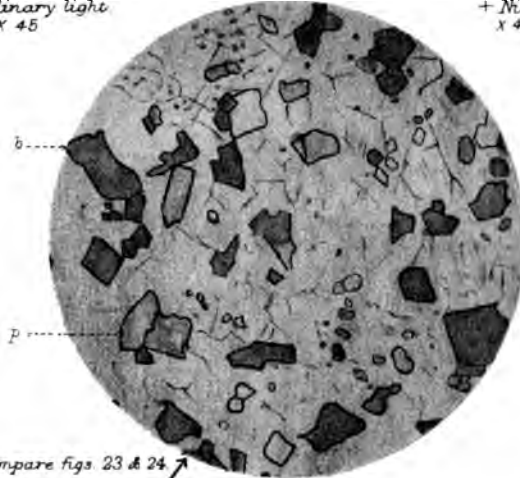
PLATE V.



21
Ordinary light
X 45

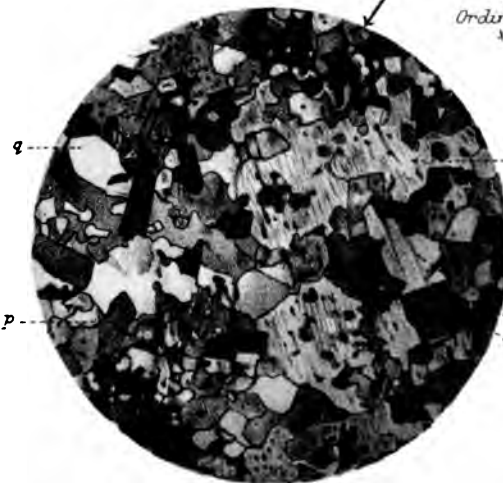


22
+ Nicols.
X 40



23
Ordinary light.
X 60

N.B. Compare figs 23 & 24



24
+ Nicols.
X 60



25
+ Nicols.
X 60

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